national marine fisheries service

southwest fisheries science center

HONOLULU LABORATORY

Program Review 2000

HONOLULU LABORATORY 2000

EXTERNAL PROGRAM REVIEW

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U.S. Department of Commerce
National Marine Fisheries Service
Southwest Fisheries Science Center
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IMPORTANCE OF CENTRAL AND WESTERN PACIFIC FISHERIES

Fisheries under U.S. jurisdiction in the central and western Pacific are generally healthy and viable, as well as economically and socially important and valuable. The condition of these fisheries appears to be the best of all regions in the U.S. However, great care and continued attention must be taken to preserve this sound situation in the widest geographical jurisdiction of the United States. Substantial efforts were taken in 1999 and 2000 to develop a new set of overfishing definitions consistent with the Sustainable Fisheries Act of 1996.

Analyses of pelagic fisheries in the central Pacific show no signs of overfishing, although some stocks may be near their sustainable yields. The Hawaii swordfish fishery has shown a complete return in catch-per-unit-of-effort (1,000 hooks) compared to catch rates in the early 1990s at the beginning of the fishery and following a steep decline in 1994. The 1994 decline in catch rates appears to have been caused by a combination of environmental and targeting factors. Although swordfish landings have declined since 1993, this is primarily because a number of swordfish longliners left Hawaii in 1993 and 1994, and other swordfish boats shifted their fishing effort to the more lucrative bigeye tuna.

The longline catch of tunas, billfish, and associated pelagics grew substantially in Hawaii from the mid-1980s through 1998 (record landings in weight but not in value), while the small-scale longline fishery for albacore operating out of American Samoa grew dramatically. Both remained stable in 1999. The Hawaii longline fleet operates under a Federal limited-entry program which caps total effort.

The bottomfish (snappers, groupers, and jacks) fishery in the Northwestern Hawaiian Islands (NWHI) is in good condition, following proactive measures by the Western Pacific Regional Fishery Management Council (WPRFMC) and NMFS. The bottomfish fishery is also subject to limited entry. The main Hawaiian Islands (MHI),which are managed by the State of Hawaii, have shown stress for a variety of species. In 1998 the State implemented a series of area closures to address this situation. The Hancock Seamount stocks of deepsea groundfish (armourhead) have not recovered following overfishing by foreign fishing vessels prior to the implementation of the Magnuson-Stevens Act in 1976. This fishery remains closed by WPRFMC action and a long-term moratorium has been proposed.

The NWHI lobster fishery has become a matter of concern because of uncertainty in the population models used to estimate the exploitable biomass. The fishery has been closed for the 2000 season, although an experimental permit fishery may be operated if approved by the Federal Court. The lobster fishery is a limited-entry, restricted-season, quota-based fishery.

On the other hand, the Hawaii precious corals fishery which has been inactive for years has recently become active through harvesting by a commercial vessel using submersible technology, and it too appears healthy. Initial surveys show that many stocks fished down prior to the Magnuson Stevens Act's implementation in 1976 have recovered and that precious corals are more widely distributed than previously thought.

The status of coral reefs in Hawaii and other areas of the central Pacific has recently been highlighted, and the Honolulu Laboratory has been taking steps to reduce the impact of marine debris (primarily lost fishing nets from the North Pacific) on these reefs. An ambitious research and mitigation program has been planned for the next 5 years.

Three western Pacific ports (Pago Pago, American Samoa; Agana, Guam; and Honolulu, Hawaii) rank in the top 10 of the most valuable fishing ports in the U.S.A. when distant water landings are included.[1]

[1]Landings by domestic and foreign purse seine and foreign longline vessels in American Samoa and Guam are not reported because of confidentiality. These estimates are based on reports from these island area governments.

Table 1. The ten most valuable fishing ports in the United States (including distant-water landings for the central and western Pacific), 1998.

Rank	Port	Landings value $ million ex-vessel
1	Pago Pago, American Samoa	~ $232
2	Dutch Harbor, Alaska	110
3	New Bedford, Massachusetts	94
4	Agana, Guam (1996 value)	~ 94
5	Kodiak, Alaska	79
6	Brownsville, Port Isabel, Texas	64
7	Honolulu, Hawaii	49
8	Key West, Florida	45
9	Reedville, Virginia	43
10	Port Judith, Rhode Island	42

The ex-vessel value of landings in these ports is approximately $350 million (Table 1). U.S. canneries are the primary private sector employer in American Samoa. While there are no canneries in Guam, there is a high value of fisheries due to the transshipment of sashimi-grade fish. Local fisheries have grown substantially in American Samoa, Guam, and the Commonwealth of the Northern Mariana Islands over the past 10 years. (Fig. 1). Fisheries also have an important economic impact in Hawaii and are perhaps even more important socially and culturally. Growth in Hawaii's fisheries was dramatic in the 1980s and 1990s, leveling off in 1998 (Figs. 2a and 2b).

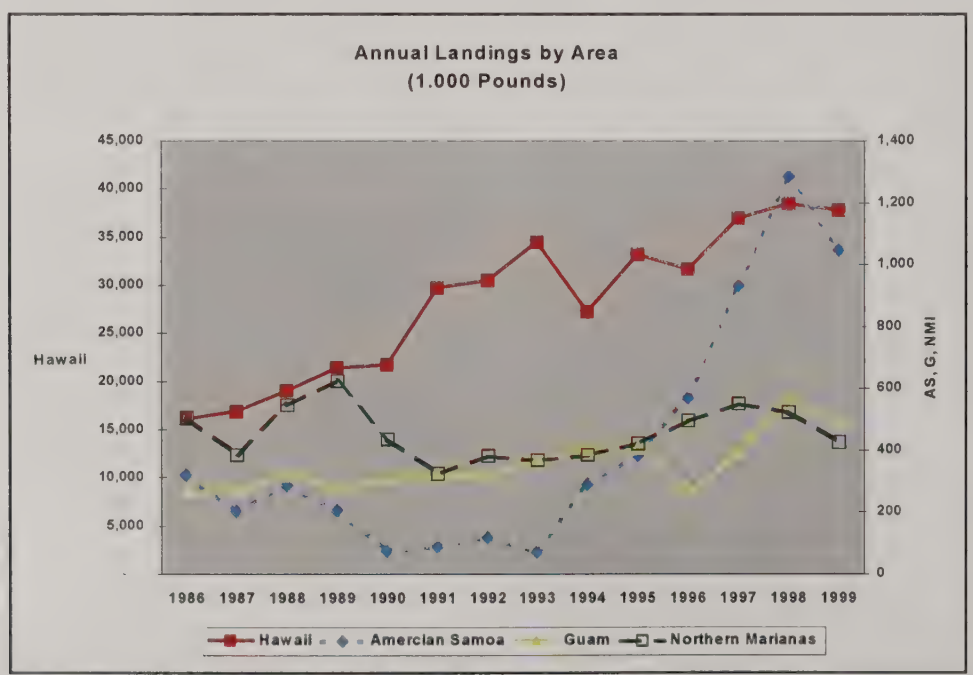

Figure 1 Annual domestic landings by area, 1986-99. American Samoa, Guam, and the Northern Mariana Islands (right axis in 1,000 pounds) and Hawaii (left axis in 100,000 pounds).

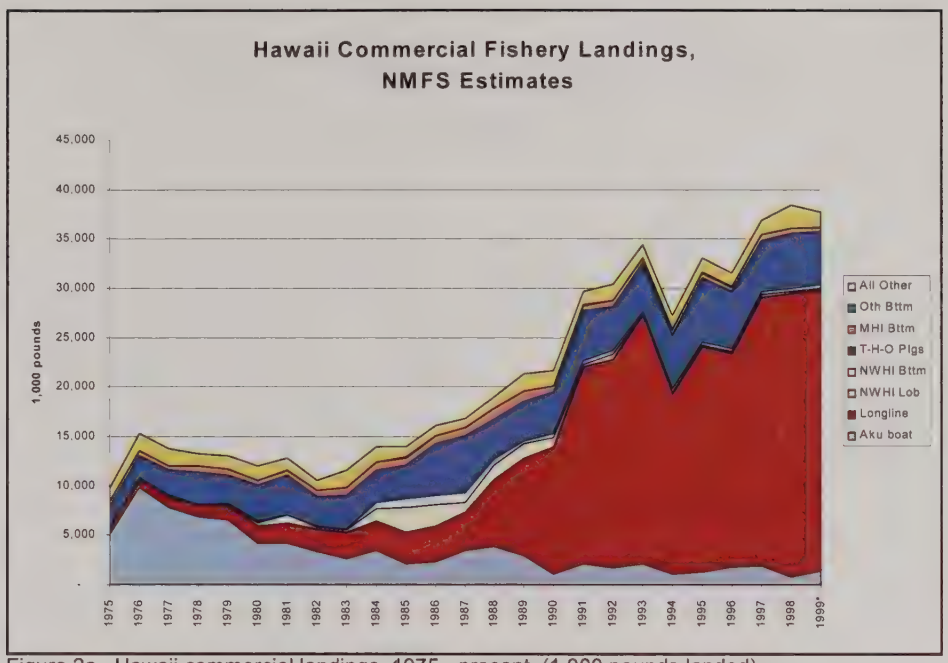

Figure 2a. Hawaii commercial landings, 1975 - present. (1,000 pounds landed)

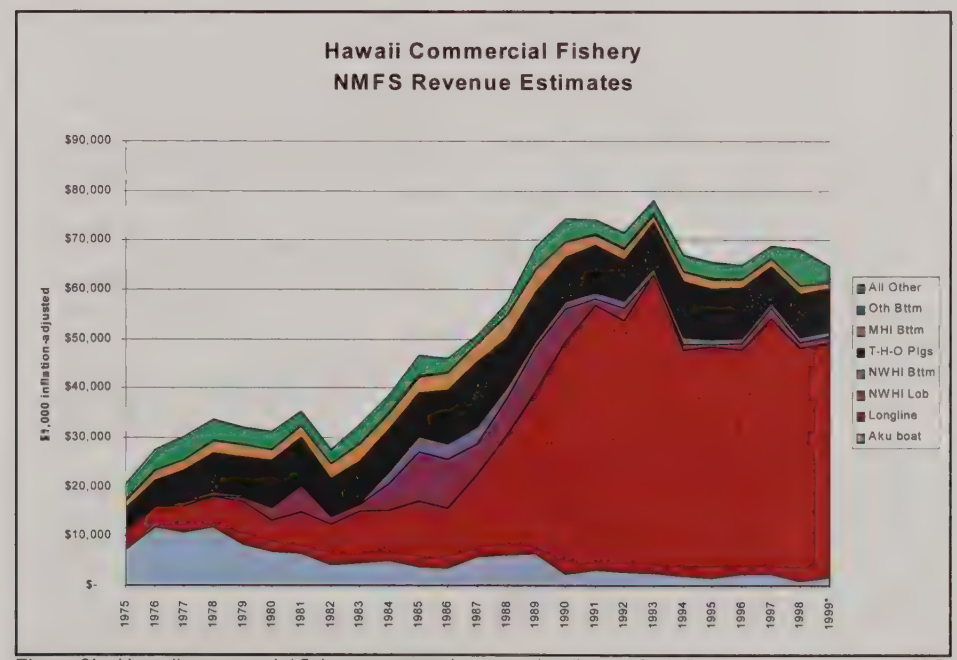

Figure 2b. Hawaii commercial fishery revenue (ex vessel, adjusted for inflation to current year), 1975-99.

THE NMFS SOUTHWEST FISHERIES SCIENCE CENTER
HONOLULU LABORATORY

OVERVIEW

The Honolulu Laboratory (HL) was established in 1948. Over the past five decades HL has had an illustrious history of performing fisheries exploration and development, conducting fisheries research, and providing scientific information and expertise in support of the management of fisheries and the recovery of protected species in the central and western Pacific. The main HL facility is located on the University of Hawaii campus at Manoa. HL also has a smaller research facility with seawater capabilities for conducting research on live large pelagic fishes, monk seals, and sea turtles. That facility is located at Kewalo Basin, about 3 miles from HL.

Mission of Honolulu Laboratory

The mission of HL is to do the science to support the stewardship of fisheries and protected species in the central and western Pacific. It is linked to the NOAA Strategic Plan to Build Sustainable Fisheries, Recover Protected Species, and Maintain Healthy Living Marine Resource Habitats and to the Department of State's priorities concerning international management in the Pacific highly migratory species (HMS).

Goals of Honolulu Laboratory

The goals of HL are to provide scientific information and advice to:

- Manage domestic fisheries in the U.S. Exclusive Economic Zones (EEZs) in the central and western Pacific.
- Support U.S. interests related to the Convention on the Conservation and Management of Highly Migratory Fish Stocks in the Western and Central Pacific.
- Recover and manage populations of the highly endangered Hawaiian monk seal and protected Pacific sea turtles and assess and mitigate seabird mortality resulting from fisheries interactions.

Geographic Area of Responsibility

The geographic area of responsibility of HL (see Fig.3) is the largest of all U.S. fisheries laboratories and, perhaps, the largest of all fisheries research laboratories in the world. The vast area is bounded by the entire Hawaiian Archipelago in the north, American Samoa and U.S. possessions in the south, and the Marianas Archipelago in the west. The area of these EEZs is more than 1.7 million square nautical miles, which is slightly larger than the total EEZ of the entire U.S. mainland and Alaska.

Research and Activities Related to Management of Domestic Fisheries

HL is responsible for conducting biological, ecological, and economic fisheries research, performing fisheries stock assessments required to provide scientific information and guidance for four Fishery Management Plans (FMPs) and developing a new coral reef ecosystems FMP. HL is also accountable for the collection of fisheries statistics and for fisheries monitoring activities that are essential for managing fisheries. The latter include operations related to fishing logbooks mandated by Federal regulations and to the Western Pacific Fishery Information Network (WPacFIN). FMPs include the following:

Pelagic Fisheries of the Western Pacific–This FMP regulates fishing for large oceanic pelagic species including tunas, swordfish, marlins, sharks, mahimahi, opah (moonfish), ono (wahoo), and other pelagic species within the U.S. EEZ in the central and western Pacific. This FMP applies to

Figure 3. Geographic area of responsibility for the Honolulu Laboratory.

important domestic longline, troll, handline, and pole-and-line fisheries operating out of Hawaii, as well as the albacore longline fishery operating out of American Samoa.

Crustacean Fisheries of the Western Pacific–The NWHI trap fishery for spiny and slipper lobsters is managed under this FMP. The FMP is in the process of being adjusted to include lobster fishing in other areas of the western Pacific.

Bottomfish and Seamount Groundfish Fisheries of the Western Pacific–Snapper, grouper, emperors and jack species in American Samoa, Guam, Hawaii, and the Commonwealth of the Northern Mariana Islands (CNMI) are managed under this FMP. In addition, this FMP includes provisions for management of the Hancock Seamount armourhead resource, which was harvested by foreign fisheries until a moratorium was put in place nearly a decade ago due to the overfished condition of this armourhead stock.

Precious Coral of the Western Pacific–Precious corals in this fishery include pink corals (*Coralilum secundum, C. regale*, and *C. laauense*), gold corals (*Gerardia spp., Narella spp. and Calyptrophora spp.*), bamboo corals (*Lepidisis olapa and Acanella spp.*), and black corals (*Antipathes dichotoma, A. grandis, A. ulex*). After several years' hiatus, fishing was resumed for precious corals in 1999.

Coral Reef Ecosystems FMP–This FMP is under development by the WPRFMC and is expected to be adopted in 2000.

Activities Related to the Convention on the Conservation and Management of Highly Migratory Species in the Western and Central Pacific

HL has been assigned responsibility for providing scientific information to support U.S. interests in the international management of highly migratory species (HMS) in the western and central Pacific. This responsibility requires that HL engage in biological, ecological, and economic research, as well as stock assessments for tunas, billfishes, sharks, and eventually other pelagic species incidentally caught or with target species.

HL plays a leadership role in international

organizations related to the international management of Pacific HMS, including the Interim Scientific Committee for Tuna and Tuna-Like Species in the North Pacific (ISC) and the Secretariat of the Pacific Community/Standing Committee on Tuna and Billfishes (SPC/SCTB). HL is active in the Multilateral High-Level Conference (MHLC), which is developing the framework for a convention for international management of HMS in the western and central Pacific. HL also has a long tradition of close cooperative research relationships with fisheries research laboratories in several Pacific Rim countries including Japan, Taiwan, Korea, Chile, Mexico, Canada, and others.

Research and Activities Related to the Recovery of Protected Species

HL has comprehensive research programs related to the recovery and management of the endangered Hawaiian monk seal and protected Pacific sea turtles. In addition, HL has responsibilities related to fisheries interactions with seabirds. Research and operations related to the Hawaiian monk seal include biology, ecology, population assessment, factors acting to retard recovery of the monk seal populations(s), and the development and application of actions to mitigate the latter. Biological, ecological, and population assessment research is conducted on Pacific sea turtles, with emphasis on the Hawaiian green sea turtle. HL is also playing a leadership role in research on fibropapilloma, a deadly disease infecting sea turtles worldwide. Laboratory activities related to fisheries interactions with sea turtles include research on methods for estimating takes and kills of seabirds resulting from fisheries interactions. HL also conducted notably successful research on methods to reduce sea bird mortality resulting from longline fishery interactions.

HONOLULU LABORATORY BUDGET, STAFFING, AND ORGANIZATION

Honolulu Laboratory FY 2000 Budget

The FY 2000 budget for HL is nearly $8.8 million. NMFS base funds allocated to HL by the Southwest Fisheries Science Center (SWFSC) cover about $4.1 million of this budget. The balance comes from several sources including add-on funds from the NMFS Office of Protected Species and NMFS Southwest Region (SWR) amounting to about $1.27 million, from Congressional Programs Projects and Activities (PPAs) totaling about $1.3 million, other PPAs $1.89 million, and other NOAA funding about $0.22 million. A summary of the budget by funding source and selected programs is provided in Table 1.

Honolulu Laboratory Staffing

HL staff includes 57 NOAA/NMFS employees, 1 NOAA Corps officer, and 64 University of Hawaii/Joint Institute for Marine and Atmospheric Research (UH/ JIMAR) employees. Most of the UH/JIMAR staff members are paid with HL funds that are awarded to UH/JIMAR through a grant. Some of the UH/JIMAR staff members are supported by funds awarded by the JIMAR's Pelagic Fisheries Research Program (PFRP) through a competitive process. (See section on Honolulu Laboratory Relationships with the University of Hawaii for further discussion). Thirty-nine UH/JIMAR staff members are full time, 13 are part time or seasonal hires, and 12 are student assistants. The number of staff members by category appears in Table 2.

Honolulu Laboratory Organization

HL is organized into the Director's Office, Administrative Services, Information and Technical Services, and five research Investigations. An organization chart for HL is given in Figure 4; a listing of staff is given in Table 4. A NOAA CoastWatch Site is also located at HL.

Table 2. Honolulu Laboratory FY 2000 Budget

Funding Source	Amount ($1,000)
NMFS base	$4,063.5
NMFS add-on	
Sea Turtle	137.2
Prevent Extinction of Leatherbacks	368.9
Reduce Bycatch of Turtles	65.6
WPacFIN	376.6
EFH: Pelagics Fisheries	90.0
EFH: GIS	62.0
Impact of Lobster Trapping on Coral Reefs	40.0
PPA Congressional	
Monk seal	695.5
Sea turtle	266.6
Swordfish	398.5
Other NMFS Base	
Monk Seal	1295.0
Sea turtle	282.0
Fisheries Info Technology	105.7
WPacFIN – Base	209.2
Other Funding	
ESDIM – Data Rescue	98.0
CoastWatch (NESDIS)	125.0
Coral Reef	100.0
Toolbox	50.0
Economic Cost Data Collection	10.0
TOTAL	$8,839.3

Table 3. Honolulu Laboratory NOAA and UH/JIMAR Staff

Organization	Number
NOAA	
NMFS	57
NOAA Corps	1
Total NOAA	58
UH/RCUH-JIMAR Staff	
Administration Staff	1
Fishery Oceanography	27
WPacFIN	9
CoastWatch	1
MARDAP	7
Pelagic Fishery Research Program	7
Full-time	39
Part-time	2
Seasonal hires	11
Student Assistant	12
Total non-NOAA	64
TOTAL	122

HONOLULU LABORATORY ORGANIZATION CHART

LABORATORY DIRECTOR
ADMINISTRATION
SCIENTIFIC INFORMATION & TECHNICAL SERVICES
FISH BIOLOGY & ECOLOGY INVESTIGATION
(LIFE HISTORY, FISH ECOLOGY)
ECOSYSTEM & ENVIRONMENT INVESTIGATION
(FISHERY OCEANOGRAPHY, ECOSYSTEM & HABITAT)
STOCK ASSESSMENT INVESTIGATION
(POPULATION DYNAMICS & FISHERY INTERESTS)
FISHERY MANAGEMENT & PERFORMANCE INVESTIGATION
(FISHERY MONITORING & ECONOMICS, FISHERY DATA MGMT, WPacFIN)
PROTECTED SPECIES INVESTIGATION
(MONK SEAL, TURTLES)

Figure 4. Schematic showing organization of Honolulu Laboratory.

Research Investigations and Programs

Ecosystem and Environment Investigation

- Fisheries Oceanography Program
- Ecosystem and Habitat Program

Fish Biology and Ecology Investigation

- Fish Biology Program
- Life History Program
- Fish Ecology Program

Fisheries Stock Assessment Investigation

Fishery Management and Performance Investigation

- Fishery Monitoring and Economics Program
- Fishery Data Management Program
- Western Pacific Fishery Information Network Program

Protected Species Investigation

- Marine Mammal Research Program
- Marine Turtle Research Program

Director's Office and Administration

The primary objectives of the Director's Office are to provide overall scientific leadership and research direction, program management, and operational policy. In addition, the office is responsible for liaison with other NMFS and NOAA offices, the WPRFMC, UH, the State of Hawaii, and other agencies and organizations. The Director also serves as the Principal Investigator of the NOAA CoastWatch Site.

The Administration group provides comprehensive administrative services for procurement, budget planning and implementation, fiscal monitoring, personnel management, travel, and facilities management. The editorial section of Administration provides scientific editorial services for HL.

Scientific Information and Technical Support Services

The objectives of this group are to provide scientific and technical support for HL, including computer hardware and software sys-

tems; communications systems; (e.g., Laboratory LAN, agency WAN, and data communication networks linked with UH and National Weather Service); computer and communication systems security; high technology applications for data management and distribution, including Oracle System, Web Site, and Geographic Information Systems (GIS); library and graphics services; and NOAA CoastWatch operations.

Program Management and Multidisciplinary Teams

Program management at HL follows a hybrid form of matrix management, with extensive interactions across the five research Investigations, which are organized on a functional basis. Multidisciplinary Teams are used to plan, conduct, and coordinate research projects as well as to promote communications among all the parties involved. The Teams are made up of individuals from several or all of the HL research investigations and service support groups. The teams include the following:

Investigation Chiefs Team–This team consists of the Laboratory Director, Chiefs of the five research Investigations, the Administrative Officer, the head of the Scientific Information and Technical Services, the Science Program Coordinator, and the Director's management analyst. The purpose of this team is to serve as a "board of directors" for HL, to develop policy, to promote open communications among the operating units of HL, and to coordinate actions among the various groups as needed.

Swordfish Research Team–The goal of the Swordfish Research Team is to provide an operational multidisciplinary framework for identifying, prioritizing, conducting, and coordinating swordfish research. A comprehensive research plan encompassing fishery monitoring, stock assessment, and biological and fishery oceanography research has been developed by the team, which is comprised of scientists and managers from HL, WPRFMC, and UH/JIMAR.

Oracle Database Development Team–The Oracle Database Development Team was established to ensure the coordinated conversion of Hawaiian monk seal, Pacific sea turtle, and pelagic fisheries data, as well as other fisheries and related data within the HL Oracle database system. The team was expanded to include web site management and GIS development.

Lobster Research Team–The Lobster Research Team was formed in response to the need to develop new methods for determining the annual harvest guideline (quota) for the NWHI lobster fishery and for research planning. The team consists of scientists from HL, UH/JIMAR, NMFS/SWR/Pacific Islands Area Office (PIAO), and WPRFMC. Presently, the team is primarily responsible for appraising the new harvest guideline procedures, planning lobster research, coordinating research activities, and advising the HL Director on lobster research needs.

Publications and Scientific Meeting Presentations

Sixty-five manuscripts have been approved, submitted for publication, in press, or published by HL scientists during FY 2000. A listing of publications is found in Appendix 1. The numbers of publications by category are as follows:

Fishery biology/ecology - 17
Fisheries and fishery interactions - 8
Physical and biological oceanography - 5
Hawaiian monk seals - 7
Sea turtles- 17
Fisheries economics & social science - 11

The Laboratory staff also prepared 77 administrative reports, abstracts, and workshop proceedings. In addition, HL scientists made 71 presentations at scientific meetings as well as more than 120 presentations to the WPRFMC Plan Teams, Advisory Teams, Science and Technical Committees, and full WPRFMC meetings.

Table 4. Personnel, Honolulu Laboratory

DIRECTOR'S OFFICE

R. M. Laurs, Director, Supvy. Oceanographer
W. Goo, Management Analyst
R. Brainard, NOAA Corps
J. Tanaka, Secretary*

ADMINISTRATION

S. Kamei, Administrative Officer
F. Fiust, Editorial Assistant
J. Kendig, Writer-Editor
B. Oshiro, Administrative Support Assistant
S. Wong, Budget Assistant
J. Yoshida, Purchasing Agent
H. Gerboc, General Maintenance Assistant*
J. Nakamoto, Administrative Specialist*

SCIENTIFIC INFORMATION & TECHNICAL SERVICES

D. Tieman, Comp. Sys. Analy.
S. Abbott-Stout, Librarian
W. Higuchi, Computer Specialist
J. Pappas, Computer Specialist
M. Parke, Computer Specialist
R. Price, Computer Specialist
R. Skillman, Fishery Biologist
R. Uyeda, Computer Specialist
D. Yamaguchi, Scientific Illustrator
R. Yoshimoto, Computer Assistant
D. Foley, CoastWatch Coordinator*

FISH BIOLOGY & ECOLOGY INVESTIGATION

C. Boggs, Supvy. Fishery Biologist
R. Brill, Fishery Biologist
R. Chang, Fishery Biologist
E. DeMartini, Fishery Biologist
R. Humphreys, Fishery Biologist
T. Kazama, Fishery Biologist
R. Moffitt, Fishery Biologist
B. Mundy, Fishery Biologist
R. Nishimoto, Fishery Biologist
J. Sampaga, Bio. Sci. Tech. (Micro)
P. Shiota, Fishery Biologist
J. Uchiyama, Fishery Biologist
H. Williams, Bio. Sci. Tech. (Micro)
D. Curran, Fishery Biologist*
M. Musyl, Fishery Oceanographer*
J. Swimmer, Fishery Biologist*

ECOSYSTEM & ENVIRONMENT INVESTIGATION

J. Polovina, Math. Stat.
D. Kobayashi, Fishery Biologist
F. Parrish, Fishery Biologist
M. Seki, Fishery Biologist
E. Howell, Research Associate*
S. Murakami, Oceanographic Technician*

STOCK ASSESSMENT INVESTIGATION

J. Wetherall, Fishery Biologist
G. DiNardo, Fishery Biologist
P. Kleiber, Fishery Biologist
M. McCracken, Mathematical Statistician
G. Epstein, Computer Specialist*
M. Labelle, Senior Researcher*

FISHERY MANAGEMENT & PERFORMANCE INVESTIGATION

S. Pooley, Supvy. Industry Economist
F. Cabacungan, Computer Specialist
F. Dowdell, Computer Specialist
D. Hamm, Supvy. Comp. Spec.
R. Ito, Fishery Biologist
K. Kawamoto, Fishery Biologist
B. Kikkawa, Fishery Biologist
B. Miyamoto, Computer Specialist
M. Quach, Computer Specialist
D. Tagami, Operations Research Analyst
L. Tsukano, Computer Assistant
V. Abellera, Computer Specialist*
N. Chan, Data Entry/Processing Clerk*
D. Gonzales, Computer Specialist*
C. Graham, Computer Specialist*
W. Machado, Fishery Assistant*
J. Pitko, Computer Specialist*
P. Tao, Computer Specialist*
C. Tokita, Data Processing Clerk*
W. Walsh, Asst. Researcher*
C. Althen, Computer Specialist*
N. Nakasone, Clerk*

PROTECTED SPECIES INVESTIGATION

G. Antonelis, Supvy. Wildlife Biologist
J. Baker, Marine Biologist
G. Balazs, Zoologist
B. Becker, Wildlife Biologist
R. Dollar, Bio. Sci. Tech
J. Henderson, Fishery Biologist
T. Johanos-Kam, Wildlife Biologist
M. Arnone, Data Entry Clerk*
R. Boland, Biological Technician*
C. Cornish, Biological Research Specialist*
M. Donohue, Marine Debris Coordinator*
S. Eames, Data Entry Clerk*
J. Kamiya, Secretary*
L. Kashinksy, Vet. Medical Technician*
S. Murakawa, Research Associate*
D. Parker, Research Associate*
B. Ryon, Biological Technician*
M. Shaw, Biological Research Technician*
H. Swensen, Computer Specialist*
C. Yoshinaga, Logistic Coordinator*

11 seasonal hires and 12 student assistants not included

***JIMAR**

Honolulu Laboratory Relationship with WPRFMC and SWR/PIAO

HL shares close working relationships with NMFS SWR PIAO and WPRFMC. WPRFMC prepares and recommends fishery management actions to NMFS. PIAO prepares fishery management regulations and is responsible for carrying out fishery management actions. HL provides scientific advice and input for domestic fishery actions to both WPRFMC and PIAO.

Honolulu Laboratory Relationships with UH

HL is located on the UH Manoa campus and has extensive relations with UH, resulting in significant mutual benefits. Several of HL's senior investigators hold UH adjunct professorships or senior research fellow positions, lecture UH courses in marine science and related topics, and serve as scientific advisers to undergraduate and graduate students. UH students serve as a source of talented and motivated temporary help for HL. HL computer Internet access and other computer communications are handled through the UH Computer Center, and the NOAA ship assigned to HL, *Townsend Cromwell*, is berthed and receives port support from UH. UH also provides some environmental compliance maintenance for HL as well as after-hours security. Most direct associations between HL and UH are through NOAA/UH/JIMAR.

HL has many interactions with UH/JIMAR including the opportunity for HL scientists to compete for pelagic fisheries research funding that is awarded competitively by JIMAR/PFRP. JIMAR/PFRP administers funding received from Congress. HL scientists have successfully competed for JIMAR pelagic fisheries research funds and over the past 5 years have served as principal or co-principal investigators on 11 projects totaling more than $2 million. In addition, substantial complementary, collaborative, and cooperative research on pelagic fisheries is conducted by HL and UH/JIMAR scientists.

HL utilizes the UH/JIMAR program by awarding grants to JIMAR for research in support of the mission of HL. In FY 2000 HL awarded grants totaling about $1.4 million to JIMAR to support research and operations at HL. A summary of the funding by projects is provided in Table 5. HL also participates in the JIMAR visiting scientist program.

NOAA CoastWatch

The NOAA CoastWatch site, which is funded by NOAA/NESDIS, is located at HL. The site has direct readout of NOAA satellites (shared with NOAA/National Weather Service) and satellite image processing systems. Satellite-derived ocean data products are produced at the CoastWatch site for distribution to federal, state, and local agencies and university researchers involved in marine science, policy, and management. Over the past year, there has been a significant expansion in the amount of satellite information available from the CoastWatch Site, including new sea surface temperature, ocean circulation, ocean wind, and ocean color products. CoastWatch data products are increasing in use in HL fisheries and protected species research. See the CoastWatch section of this report for more details as well as the sections on Fishery Oceanography and Essential Fish Habitat for information about the expanded use of CoastWatch satellite-derived ocean data products in HL research.

Table 5. Honolulu Laboratory Funds Awarded to UH/JIMAR in FY 2000

Programs	Amount ($1000)	Total ($1000)
Fisheries Oceanography		$ 876.3
Recovery of Hawaiian Monk Seal	575.3	
Pacific Sea Turtle Biology and Ecology	180.0	
Prevent Extinction of Leatherbacks	81.0	
Reduce Bycatch of Turtles	40.0	
Western Pacific Fishery Information Network Project	298.6	$298.6
Marine Resource Dynamics and Assessment Program (MARDAP)		$232.8
Remote Sensing	50.0	
Data Rescue	80.0	
Lobster Trapping	40.8	
Research Support	18.0	
Toolbox	44.0	
NOAA CoastWatch Operations	65.0	$ 65.0
Coral Reef	65.5	$ 65.5
TOTAL		$1,538.2

DOMESTIC FISHERIES MANAGEMENT

BACKGROUND

The Honolulu Laboratory (HL) is responsible for scientific research on a wide range of insular and highly migratory and other pelagic species in the central and western Pacific. These species include the tunas, major marlins including swordfish, sharks, and miscellaneous pelagics as well as lobsters, bottomfish (snappers, groupers, and jacks), precious corals, and coral reef ecosystem species. NMFS is responsible for stewardship of these fishery resources and for providing scientific leadership concerning sustainable fish and preserving essential fish habitat. Three HL staff members serve as the chairpersons of the Western Pacific Regional Fishery Management Council's (WPRFMC) plan teams for these fisheries and other staff provide much of the material from Hawaii for the WPRFMC's annual report of these Fishery Management Plans (FMP).

Goal and Objectives

The objectives of HL's fisheries research program supporting the NOAA Strategic Plan to Build Sustainable Fisheries and to maintain Healthy Living Marine Resource Habitats include biological and ecological research in support of four Fishery Management Plans (Bottomfish, Crustaceans, Pelagics, and Precious Coral) and support of the development of the draft Coral Reef Ecosystem FMP.

In order not to repeat the experience of other regions in collapsing fisheries and the resulting significant negative economic consequences that have occurred in other areas of the U.S., a proactive approach to fisheries research and management must be followed in the western Pacific and Hawaii region. This course of action will: (1) assure sustainability of the fisheries stocks, (2) ensure the viability and health of fisheries industries, and (3) provide a significant source of cultural values and recreation for the region's diverse people.

PELAGIC FISHERIES

Background

HL is responsible for scientific research on a wide range of highly migratory and other pelagic species in the central and western Pacific. These species include the tunas (albacore, bigeye, skipjack, and yellowfin) as well as the major marlins (swordfish, blue and striped marlin), and miscellaneous pelagics such as mahimahi, ono (wahoo), opah (moonfish), pomfrets, and sharks. These pelagic species are taken in three major types of fisheries regulated by the WPRFMC in the central and western Pacific: domestic commercial longline in American Samoa and Hawaii; commercial and recreational/subsistence troll and handline fisheries in each of the WPRFMC's areas; and a very small pole-and-line (*aku boat*) fishery for skipjack tuna in Hawaii. These fisheries are in general the most important for each island area (for example, the Hawaii longline fishery lands roughly 75% of total commercial landings in the state) but they are very small compared to international fisheries in the high seas surrounding these island areas. In the North Pacific, it is primarily the longline fleets of Japan, Taiwan, and Korea which take most of the pelagic species, while in areas around Samoa and Guam, U.S. distant-water and foreign purse seine fleets off-load to canneries and transshipment facilities.

NMFS is responsible for stewardship of pelagic resources and for providing scientific leadership concerning sustainable fishing and monitoring fisheries interactions with protected species in these fisheries. One HL staff member serves as the chairperson of the WPRFMC's plan team for pelagic fisheries and other staff provide most of the material from Hawaii for the annual report of the pelagic FMP.

HL collaborates with the University of Hawaii's Pelagic Fisheries Research Program (PFRP) in conducting research on tunas, swordfish, and other pelagics in the central

and western Pacific, and with the Southwest Fisheries Science Center (SWFSC) La Jolla Laboratory for distant-water tuna research. HL provides data management services for the domestic longline observer data collected by NMFS Southwest Region-Pacific Islands Area Office (SWR-PIAO) observers and receives High Seas Compliance Act logbooks from longline vessels operating out of west coast ports.

Goals and Objectives

The objectives of HL's fisheries research program support the NOAA Strategic Plan to Build Sustainable Fisheries and to maintain Healthy Living Marine Resource Habitats, as well as the Department of State's priority issue concerning International Fisheries Management of Pacific highly migratory species include (1) biological and ecological research in support of the Pelagic Species Fishery Management Plans and (2) biological and ecological research in support of the international management of Pacific tunas and tuna-like species.

Biological Research in Support of Stock Assessments

Swordfish Biology

HL's biological studies on swordfish in FY 2000 have continued emphasis on age- and growth-related topics. The objective is to provide, by the middle of FY 2001, accurate and precise sex-specific estimates of size-at-age, growth rate, and age-specific maturity for use in stock assessment analyses. Major effort has been directed at expanding the number of specimens of swordfish aged and continuing to validate age estimates. Work has also continued with the Hawaii Institute of Marine Biology (HIMB) collaborators on the development of markers to identify the sex of commercially caught swordfish, which are landed headed and gutted in the Hawaii-based pelagic longline fishery.

Growth studies–"Annuli" on cross-sections of anal fin rays are being examined in age and growth studies of swordfish. Preparation and analyses of anal fin ray cross-sections have continued for swordfish spanning the entire range of body sizes exploited by the Hawaii-based pelagic longline fishery, about 70 to more than 250-cm eye-to-fork-length (EFL). Duplicate measurements have been completed for over 1,500 fish using a light microscope and about 1,200 fish using a digital image analyzer. A substudy to characterize possible within- and between-reader ageing bias has continued, as well as exchanges with other institutions to distinguish possible differences in ageing protocols from potential variations in growth rates among North Pacific regions. Specimen and protocol exchanges have been initiated with four international institutions including the University of Taiwan; Centro de Investigacion Cientifica y de Educacion Superior de Ensenada, Mexico; the National Research Institute of Far Seas Fisheries (NRIFSF), Japan; and the Instituto de Fomento Pesquero, Chile. Each laboratory will prepare 20 representative fin ray specimens for a reference "standard" collection which will be used to cross-calibrate swordfish ageing studies.

Complementary to the primary methodology of estimating ages of large numbers of swordfish using fin rays has been an evaluation of the age record provided by otolith sagittae. The primary result is a matched comparison of estimated body sizes at age-1 as indicated by 365 daily growth increments (DGIs) on otoliths versus body sizes at age-1 year based on fin ray annuli. Counts of DGIs have been completed for a total of 40 young-of-the-year (YOY) and yearling swordfish. Length at 365 DGIs has been estimated as 98 cm EFL (95% confidence limits, CI = 93-103 cm EFL). This estimate compares favorably with an estimate of 95 cm EFL (95% CI = 92-98 cm ELF) based on fin rays annuli indicating that growth rates of YOY and yearling swordfish based on otoliths validate fin ray estimates of early growth. Limited (n = 3) recaptures of tagged yearling fish at liberty for 1, 2, and 4 years (Fig. 5) further indicate that this characterization of length-at-age is reasonable for fish of this size and age range. Data for both sexes pooled are depicted in

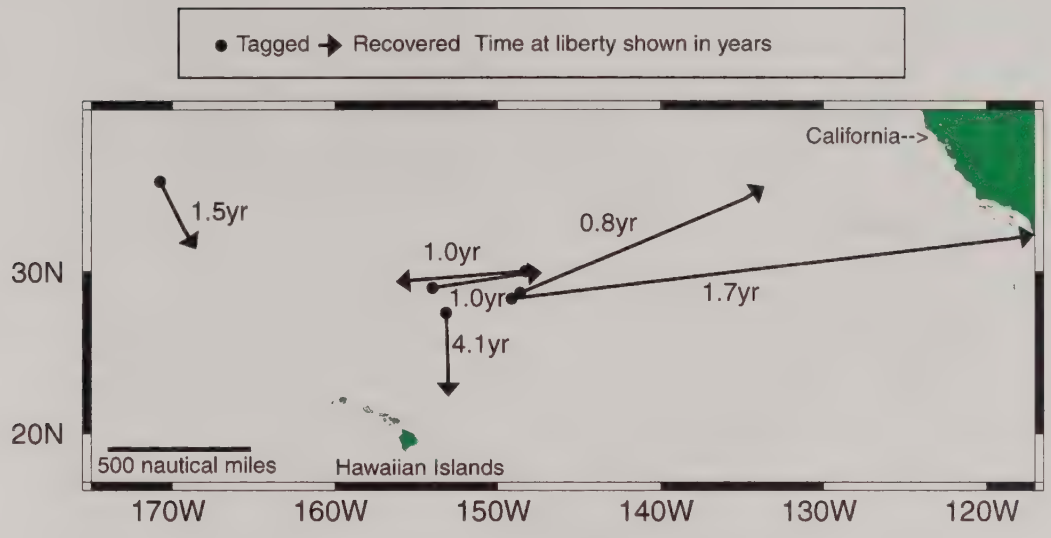

Figure 5. Net movements of swordfish from the HL tagging data base.

Figure 6 because sexes of the recaptured fish are unknown, even though male swordfish mature earlier, grow more slowly, and do not live as long as females. Final evaluation of swordfish size-at-age will be sex specific estimates of growth as well as age-at-maturity distributions which are essential elements of future age-structured stock assessments for swordfish in the Pacific.

Morphological, Chemical, and Genetic Proxies of Sexual Identity–Size composition data for known-sex swordfish caught by the Hawaii-based pelagic longline fishery during 1994-97 suggest that sex ratio can be adequately predicted from body length for fish between about 100 and 220 cm EFL (Fig. 7). A spatially and temporally refined version of this mathematical relationship might be applicable to the entire Hawaii-based longline fishery. If this is true, data on body size may be used as a proxy for sex composition, allowing landings data to be partitioned by sex based on size. Sex-specific catch data are necessary if the power of sex-specific age-at-maturity and growth rate data are to be fully utilized in future age-structured stock assessments.

Research on development of a chemical sex marker continued as a collaborative study with Hawaii Institute of Marine Biology (HIMB). During the past year, gonad specimens of 91 swordfish (74 females and 17 males ranging from 84 to 235 cm EFL) collected during the March-June 1999 spawning period in near-Hawaii waters, were histologically ground-truthed to verify sex and characterize gonadal development for comparison with sex identifications using the sex marker assays. Additional specimens, emphasizing males in the spawning season and nonspawning period fish of both sexes, are still being collected. The sex and gonadal development of these will be similarly ground-truthed in early FY 2001.

This study is being complemented by another project at the University of Florida, which is testing a chemical (vitellogenin) sex marker for swordfish. Both chemical and genetic sex markers would facilitate identification of the sex of individual fish and have their greatest importance in tagging and tracking studies. Sex identifications using muscle biopsies collected when fish are tagged could greatly improve our interpretation of movement data that surely differ among different-sized swordfish of the two sexes.

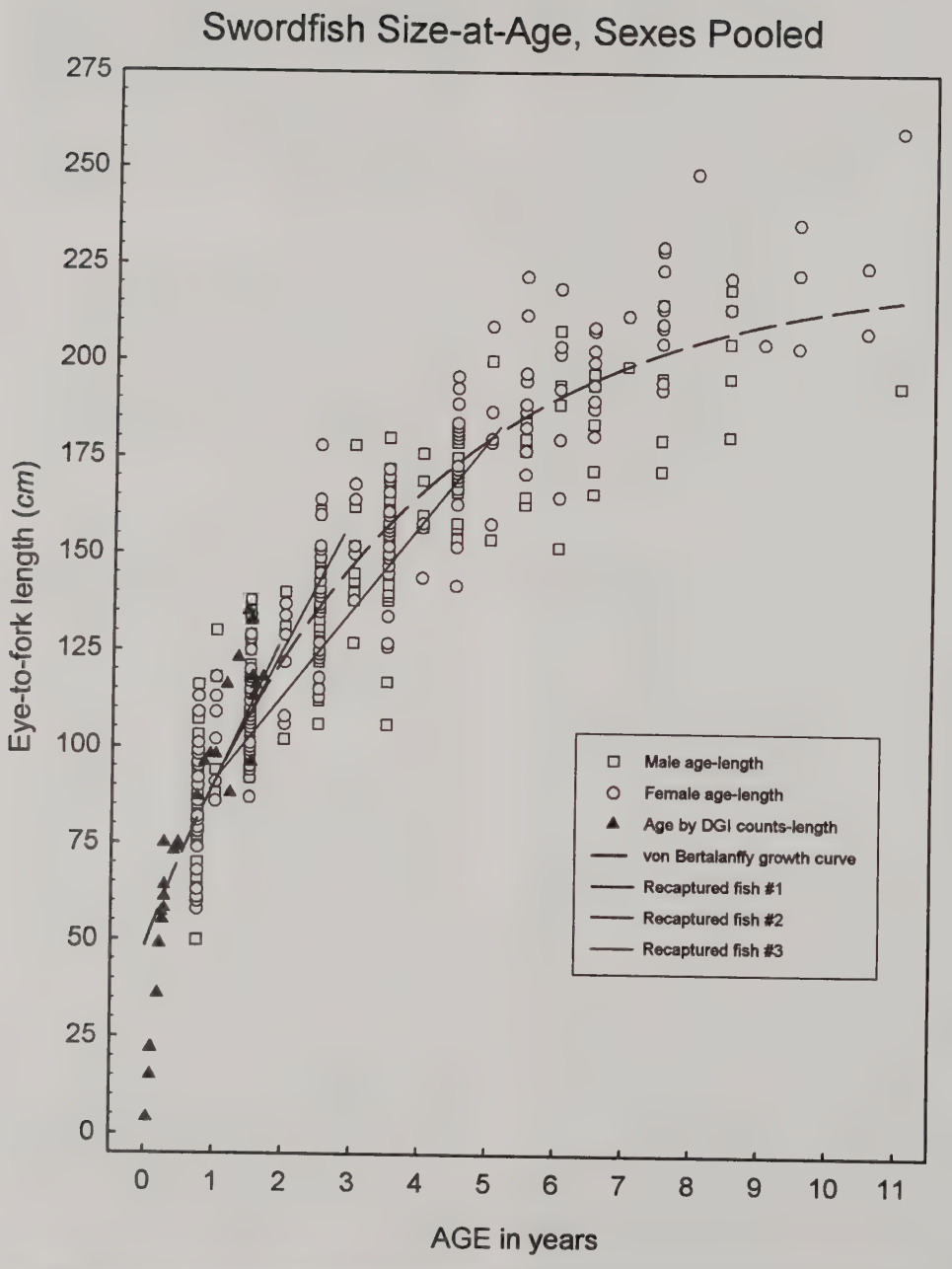

Figure 6. Swordfish size at age, showing growth curve for pooled sexes and lines showing size increases of recaptured fish.

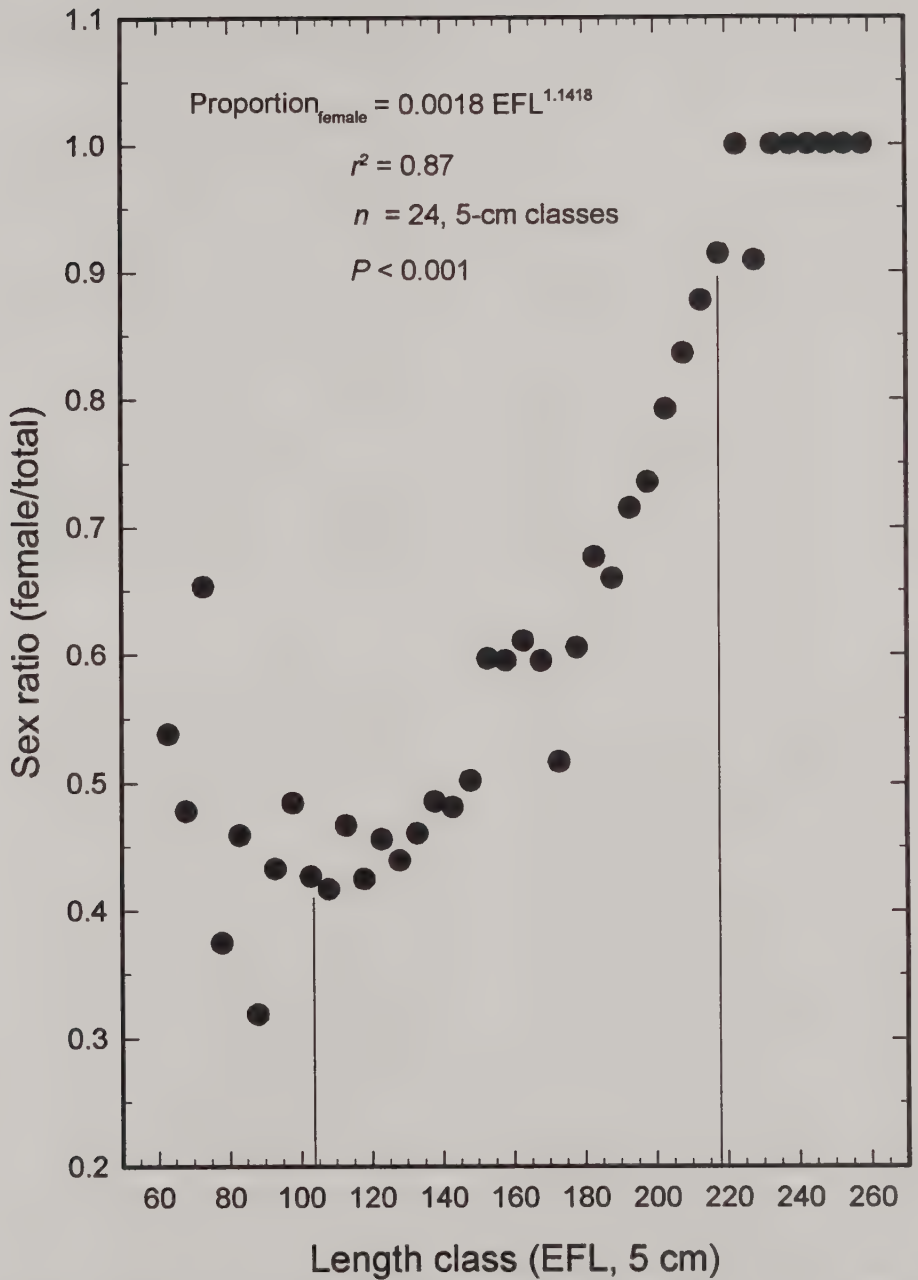

Figure 7. Swordfish sex ratio vs. length showing size range (vertical lines) over which sex ratio can be adequately predicted from body length.

Conventional Tagging Studies

The goal of HL's conventional tagging effort is to understand the stock structure, growth, and mortality of pelagic fishes, especially swordfish and blue shark. Conventional tagging provides information on the net movements of fish between the point of release and recapture. Even a few long-distance movements can indicate the possible range of a population, and may provide evidence for rejecting certain stock structure hypotheses. In addition to tagging on research cruises HL has been encouraging commercial longline fishermen to tag and release billfishes and tuna on an opportunistic basis since 1990. More recently, longline fishermen with a proven track record of voluntarily tagging and releasing small swordfish have been contracted to tag and release viable swordfish weighing 50 pounds or more. HL is charged premium market value for these fish. Since these fishermen and the swordfish research cruises of *Townsend Cromwell* mainly tag juvenile fish, this contract arrangement provides HL scientists with a more affordable way to gather survivability and other important data on larger numbers of adult swordfish. To date 27 swordfish have been tagged on contract. HL also assists in tagging programs by other laboratories and agencies.

New tag releases in 1999 included 26 swordfish, 6 marlin, 31 tuna, 8 blue shark, and 14 tiger shark. The blue shark were tagged in collaboration with the shark research program of the NRIFSF in Japan. The tiger sharks were tagged by a fishery observer on a commercial longline vessel which briefly conducted a demersal fishery for coastal shark. This fishing method will be prohibited by an amendment to the PFMP now under NMFS review, but the fishery provided a rare opportunity to try to obtain growth and movement data on tiger sharks in the NWHI.

Since the beginning of HL's involvement in conventional tagging of longline-caught pelagic fish in 1990, about 600 swordfish and several hundred other billfishes (blue and striped marlins and spearfish), and tunas (albacore, bigeye, and yellowfin) have been tagged in the areas fished by the Hawaii-based longline fishery. Since HL began collaborating in the NRIFSF shark tagging program, HL personnel have been responsible for tagging 94 of the 2,500 total sharks tagged by NRIFSF.

Net movements of blue shark from our tag data base are shown in Figure 8. To date there have been 65 tag recoveries (4 swordfish, 10 blue and 34 striped marlins, 5 bigeye tuna, 9 blue shark, and 2 oceanic whitetip shark) by Hawaii-based longline fishermen or by workers at the fish auction in Honolulu, where the longline fleet unloads the majority of its catch. The Hawaii troll fishery, including charter sport fishermen and recreational trollers have returned 26 marlin tags to HL (15 blue and 11 striped marlin). Six additional recaptures, including two swordfish, have been made by other fisheries (a Japanese longliner and a California drift netter). Net movements of swordfish from our tag data base are shown in Figure 5.

Archival Tagging

During FY 2000, HL scientists continued to employ electronic data recording (i.e., archival) tags to address questions concerning short- and long-term movements of highly mobile pelagic species. Understanding how environmental characteristics determine the distribution and movement of tunas in a dynamic ocean environment will allow fisheries biologists and resource managers to define and predict fishery interactions, specific fishing gear vulnerability under various oceanographic conditions, as well as the importance of tuna aggregations (e.g., around seamounts or manmade floating objects such as fish aggregating devices (FADs)) and relevant information. Interpretation of catch-per-unit-effort (CPUE) statistics will be improved, leading to more effective resource exploitation and sound fishery management. Understanding long-term movement patterns will help resolve issues of stock structure and spawning site fidelity for improved stock assessments. HL personnel are actively involved with both ongoing and newly evolving archival tag projects around the world.

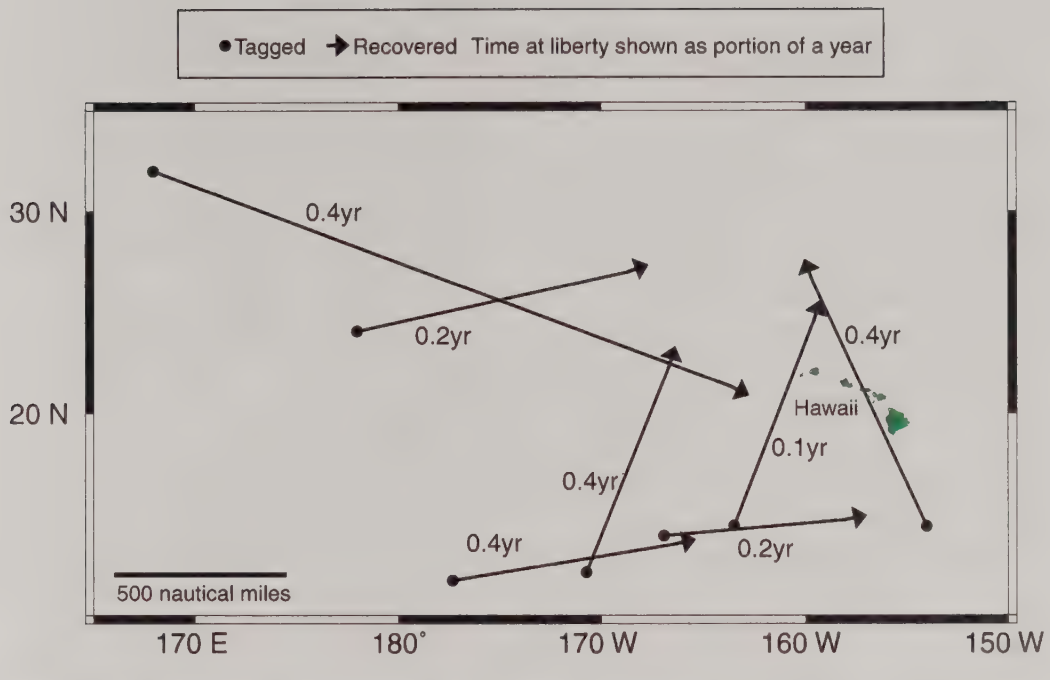

Figure 8. Net movements of blue shark from the HL tagging data base.

These include projects being conducted or developed by scientists from the Commonwealth Scientific and Industrial Research Organization (CSIRO) (Australia), Edgerton Research Laboratory of the New England Aquarium, Inter-American Tropical Tuna Commission (IATTC), Institut de Recherche pour le Dévelopment (France), SPC (New Caledonia), and University of Hawaii (UH).

Locally, HL and JIMAR's Pelagic Fisheries Research Program (PFRP) are conducting a joint project using archival tags to discern movement patterns and residence times of bigeye tuna. A rapidly expanding troll and handline fishery, targeting mostly juvenile bigeye tuna at Cross Seamount and around NOAA weather buoys, has created concerns about possible deleterious interactions with the longline fleet targeting adult animals, as well as the status of the tuna resource near the Hawaiian Islands. Since 1998, 77 archival tags have been deployed on juvenile and adult bigeye tuna captured either near the western coast of the Island of Hawaii, at Cross Seamount, or around a NOAA weather buoy (Fig. 9). The fish ranged in size from 54 to 133 cm fork length. An additional 14 archival tags will be deployed during FY 2001.

To date, 12 tagged fish have been recaptured, from which 9 archival tags have been returned. One fish was at liberty for approximately 8 months, 1 for approximately 3 months, and the remaining 6 fish approximately 1 month. All recaptures have been near the points of release. Analysis of the data is ongoing, but several significant findings have emerged. As observed during previous studies of bigeye tuna carrying ultrasonic transmitters, the fish spent daylight hours at depth and returned to the surface at night. Bigeye tuna, however, were found to be able to descend deeper (up to 735 m) into much colder water (down to ≈ 6-7°C) and to withstand much lower oxygen levels (≈ 1 ml l^{-1}) than yellowfin tuna in the same areas. During daylight, bigeye tuna make regular upward excursions into the warm surface layer apparently in order to maintain body

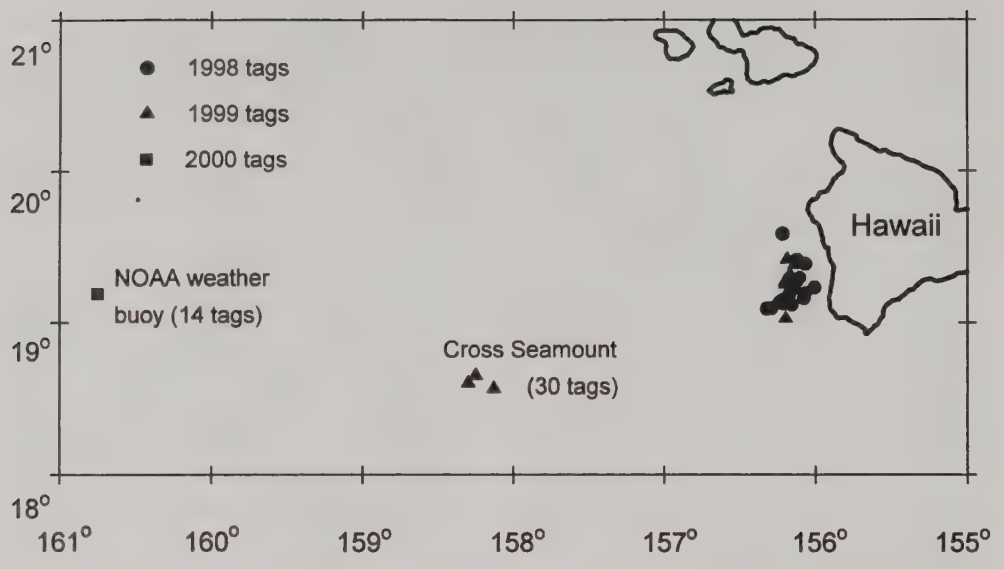

Figure 9. Locations of archival tags deployed on bigeye tuna. Tagged fish have been recaptured at all three locations.

temperatures, which generally never go below approximately 17°C (Fig. 10). The minimum depths reached during the night were found in some fish to be strongly correlated with moon phase: fish would ascend to shallower depths during the new moon. These observations confirmed and explained the correlation between catch rates of bigeye tuna on longline gear and moon phase previously observed. They also support the hypothesis that the bigeye tuna's behavior is linked to movements of the organisms comprising the deep scattering layer on which they appear to be feeding. An understanding of such behavior and its causes will help explain the variability in tuna CPUE in pelagic fisheries, a critical requirement for reliable stock assessments.

In addition, new pop-up satellite tags are becoming available and prototypes of the latest pop-up satellite archival tags have been tested successfully. Pop-up satellite archival tags have been deployed on yellowfin tuna and tiger sharks in Hawaiian waters. Cooperative HL/JIMAR/PFRP projects are planned in FY 2001 using pop-up satellite archival tags to address questions of long-term movements and post-release mortality of bluesharks, blue marlin, and swordfish, as well as the morbidity and mortality of sea turtles entangled and released from longline fishing gear.

Tuna Physiology, Biochemistry, and Ultrasonic Telemetry

Population assessments based on CPUE data usually assume that catchability is constant and that changes in CPUE solely reflect changes in overall fish abundance. However, as has been repeatedly shown for highly mobile species such as tunas and billfishes, changes in CPUE are just as likely to reflect changes in oceanographic conditions which influence the effectiveness of specific fishing gears, or changes in gear targeting. In other words, accurate population assessments depend on an a priori understanding of how the horizontal and vertical movements of tunas and billfishes (i.e., their gear vulnerability) are affected by oceanographic conditions. Sorting out these relationships has been a persistent focus of the research on tuna physiology conducted at the HL's Kewalo Research Facility (KRF). In recognition of the

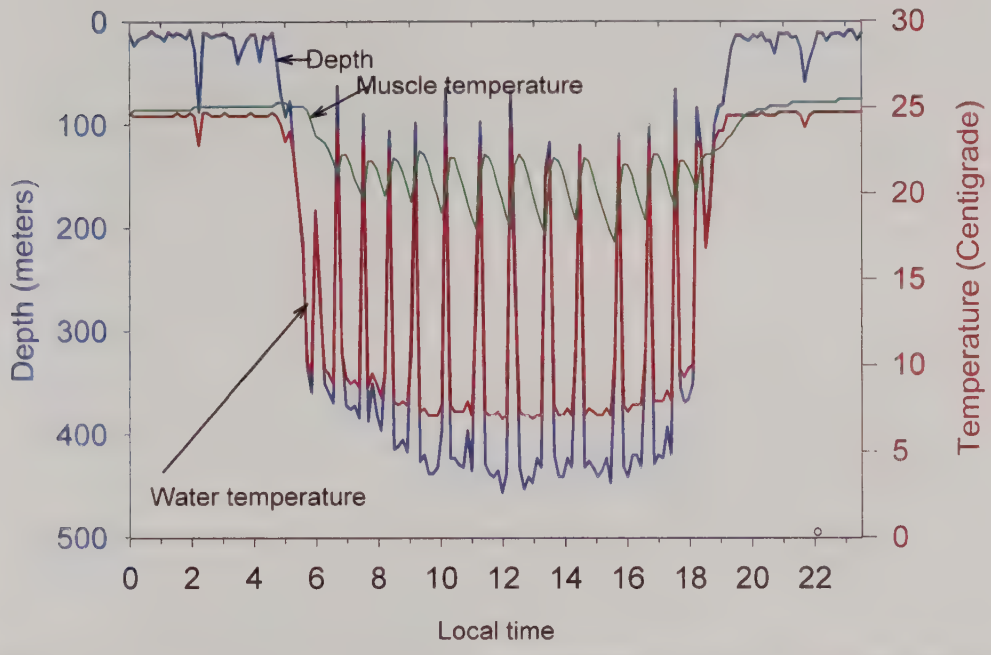

Figure 10. A sample 24-hr record of data recorded by an archival tag carried by a bigeye tuna. Note that temperatures reached during daylight descents approach 6-7°C. Oxygen levels at these depths near the MHI are approximately 1 ml l^{-1}.

continuing accomplishments of this program, research conducted at the KRF will form the basis of several major chapters on the physiology of tunas to be published as part of the latest volume of the long running Academic Press series *Fish Physiology*. The volume is intended to update the now classic book, *The Physiological Ecology of Tunas*, published more than 20 years ago.

Significant advances in the understanding of factors limiting the vertical distribution of pelagic fishes, including the previously unsuspected influence of temperature on heart function and the resultant body-size-independent limiting effect of ambient temperature on depth distributions, are now being used to improve population assessments. For example, models that incorporate the data and concepts generated by HL's tuna physiology research program are currently being developed by investigators from the HL, IATTC, and Secretariat of the Pacific Community (SPC) for population assessments of blue marlin, bigeye tuna, and swordfish. These models specifically account for variations in CPUE due to the interactive effects of gear targeting and oceanographic conditions.

The physiological research directly complements ultrasonic tracking, archival tagging, and the NMFS/JIMAR fisheries oceanography study of bigeye tuna oceanography. The project's most recent efforts have been directed at documenting and understanding the physiological/biochemical basis underlying bigeye tuna's tremendous vertical mobility.

Completed studies of the oxygen binding properties of bigeye tuna blood have shown them to be unique among tunas. The results appear to explain the documented (through archival tag studies) bigeye tuna's tolerance of low ambient oxygen conditions occurring at the extreme depths they occupy during daylight hours. Work on the effects of rapid ambient temperature changes (i.e., temperature shifts mimicking those experienced by tunas during their daily vertical movements)

have shown significant diminution of cardiac output with decreases in ambient temperature (Fig. 11). It is, moreover, the direct influence of temperature on heart function that appears to explain the depth distributions of several tuna and billfish species. How bigeye tuna are able to achieve their remarkable vertical mobility and withstand daily temperature decreases of almost 20°C remains to be established. However, contrary to posited hypothesis, extensive laboratory studies have yet to find the expected significant differences in the metabolic biochemistry of cardiac tissue in skipjack, yellowfin and bigeye tunas.

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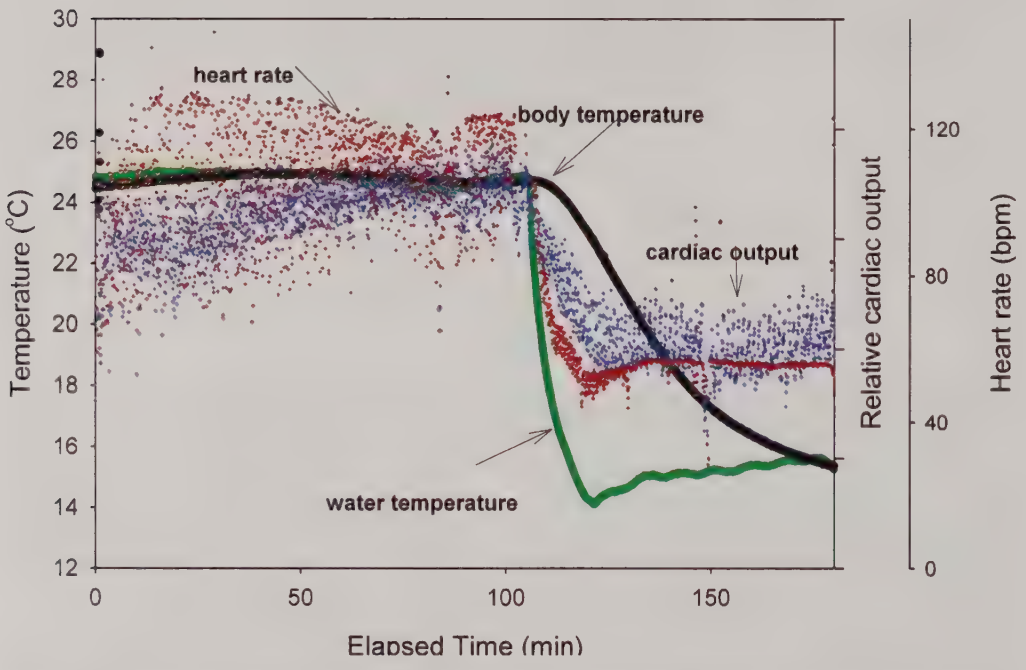

Figure 11. Typical response of a yellowfin tuna exposed (in the laboratory) to a rapid ambient temperature change mimicking those experienced by free-swimming fish. Note that both heart rate and cardiac output follow the change in ambient temperature, and that the normal variability in both seen at 25°C disappear at 15°C. This indicates that the fish has no ability at the lower temperature to increase heart rate or cardiac output to meet any increase in metabolic demand. Further decreases in ambient temperature would likely result in cardiorespiratory collapse. Note that bigeye tuna shown above (archival tag data) routinely descends to depths where the water temperature is ≈6-7°C. The metabolic adaptations that allow bigeye tuna this remarkable temperature tolerance remain unknown.

Highly Migratory Species Stock Assessment

HL staff conduct assessments of highly migratory species (HMS) in support of the resource monitoring and management needs of NMFS and the Western Pacific Regional Fishery Management Council (WPRFMC). The scope of the HMS stock assessment research is potentially very broad. The most pressing needs for stock status information have concerned the swordfish stock targeted by a key segment of Hawaii's longline fleet; blue marlin taken as bycatch in Pacific longline fisheries and important as a primary target species of Hawaii's recreational and charter-boat troll fleet; and blue shark, a nontarget species which is nevertheless the single largest contributor to the Hawaii longline catch. Of secondary concern are tuna populations important to U.S. fisheries in the Pacific and also exploited by foreign fleets and populations of other pelagic species associated with tuna and billfish about which little is known; e.g., ono, opah, and mahimahi. The scientific staff available for stock assessment work at HL is insufficient to address all HMS stock assessment needs simultaneously; hence, stock assessment research has been prioritized. In 1998 top priority for stock assessment was given to swordfish. Blue marlin and blue shark were also considered important but attention to these species was postponed. Currently emphasis is being given to blue shark.

Swordfish

During 1998, HL staff completed a preliminary assessment of swordfish in the North Pacific using historical swordfish fishery statistics from Japan, Taiwan, the U.S., and other countries. Results of the swordfish assessment were presented at a meeting of the ISC Swordfish Working Group in January 1999. These results were inconclusive, as were those of a concurrent swordfish assessment by scientists of Japan's National Research Institute of Far Seas Fisheries (NRIFSF). Considering both stock assessments, the degree of exploitation and condition of the North Pacific swordfish resource are uncertain. However, the stability of standardized swordfish CPUE statistics in the Japanese longline fishery over time, despite changes in total swordfish catch, is consistent with a low rate of exploitation.

As an aid in evaluating the swordfish stock assessments conducted by NMFS and NRIFSF, a simulation model of the swordfish stock was developed (see details below).

Blue Marlin

In 1998, the WPRFMC raised concerns about the status of Pacific blue marlin and the lack of recent blue marlin stock assessments. Similar concerns were expressed by other agencies and representatives of recreational fishing constituents throughout the Pacific, not only about blue marlin but other marlin species as well. Accordingly, at the 1999 meeting of the ISC it was agreed that an ISC Marlin Working Group (MWG) would be established with the United States having the lead responsibility. It was envisioned that the MWG would operate in cooperation with the Billfish and Bycatch Research Group, a subsidiary body of the Pacific Community's Standing Committee on Tuna and Billfish. As its first priority, the MWG would address the stock status of blue marlin, taking into account new assessments completed in 1999 by the IATTC in collaboration with the NRIFSF. This assessment indicated that blue marlin were fully exploited but healthy. When time and resources permit, HL plans to establish the MWG and work with the NRIFSF, the IATTC and other MWG members to review the marlin stock assessments and related marlin research and determine the appropriate directions for future research. Plans have been made to conduct a blue marlin stock assessment in collaboration with NRIFSF and IATTC scientists. In preparation for that and assessments of other HMS species, an HL scientist has submitted a proposal for PFRP funding to develop methods to incorporate oceanographic information in stock assessment models for pelagic species.

Blue Shark

In 1999, status of blue sharks overshad-

owed that of marlins as a public issue. Therefore, priority attention was given to a North Pacific blue shark assessment which already was a major component of a collaborative program of shark research established between HL and NRIFSF. Staff of the two laboratories exchanged historical blue shark data to support the assessment and developed a model of blue shark population dynamics and fishery impacts using Multifan-CL software.

Figure 12 shows historical blue shark catch for ten fleets, or sectors of fleets, that have taken significant numbers of blue sharks in the North Pacific. The fleets are defined in Table 6. The catch and effort data for these fleets were kept separated in the Multifan-CL analysis, rather than aggregated, either because they operate in different areas or because they have different catchability or selectivity characteristics. Indeed the CPUE time series for the 10 fleets are not all the same (Fig. 13). A common feature of several, but not all of them, is a marked upswing in CPUE during the 1990s.

In contrast to traditional stock assessment models, Multifan-CL does not make the unlikely assumption that catchability remains constant in time. Instead, it allows for year-to-year changes in catchability for each of the fleets. However, the amount of change has to be constrained to some degree by a parameter that is set in the model. With the constraint parameter set high, Multifan-CL will accommodate only small changes in catchability each year, but with lesser constraint, wider variations in catchability are accommodated. Figure 14 shows estimates of relative abundance over time from two runs of Multifan-CL, one accommodating large variations in catchability and one only small variations in catchability. In both scenarios, the blue shark population shows a significant drop during the 1980s. That is a decade of extensive small-mesh driftnet fishing in the North Pacific (Fig. 12). The drop in blue shark abundance could be a response to that fishing pressure, or possibly a result of other factors, such as an environmental regime shift, or a combination of factors.

In the scenario with little variation in catchability, the population recovers approximately to its peak level in the 1970s. In the scenario with wide variation in catchability, the population is reduced to approximately one-third of its peak in the 1970s, and it only begins to recover in the latter half of the 1990s. The two scenarios differ fundamentally in the way Multifan-CL accounts for the general upswing in CPUE during the 1990s. In one scenario the catchability is estimated to increase during the 1990s in most of the fleets (Fig. 15), which leads to the general increase in CPUE. In the other scenario the changes in catchability are restricted; therefore the Multifan-CL compensates with an increase in blue shark abundance, which also leads to increasing CPUE. Thus, there is a tradeoff between changes in catchability and changes in abundance. The most likely scenario should be somewhere between the two extremes.

Future assessment activities–In the coming year, research will continue on the blue shark stock assessment to attempt to determine the most realistic balance between changing abundance and changing catchability. In addition, a blue shark simulation model will be developed from an adaptation of the existing North Pacific swordfish model. The simulation model will be used to investigate to what degree the small mesh drift net fishery might explain the drop in abundance during the 1980s. It will also be used as a test-bed for further developments of the Multifan-CL analysis. Further development of Multifan-CL models for HMS species and the accompanying test-bed technology will be supported in part by funds from the NMFS "stock assessment toolbox" program.

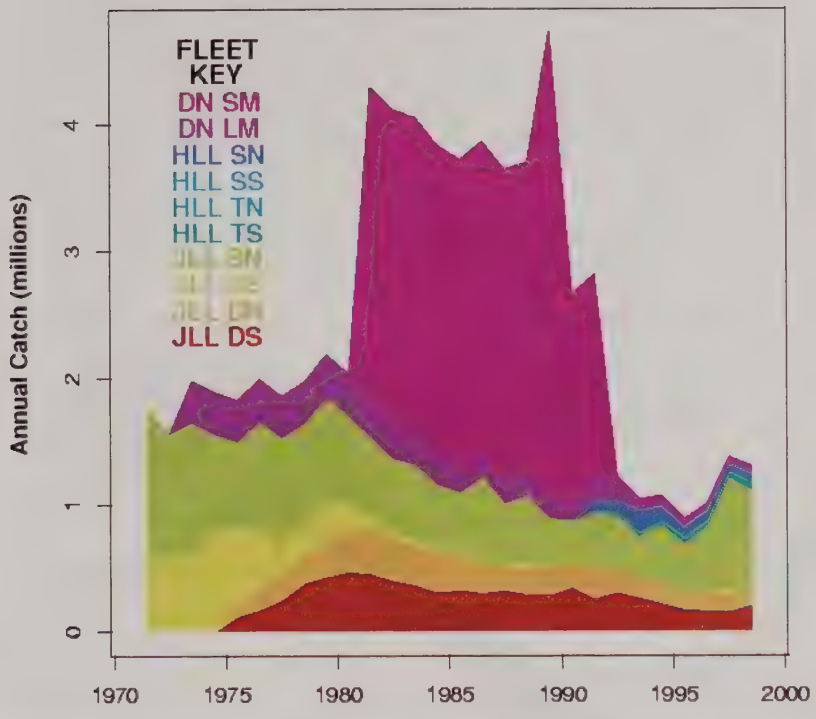

Figure 12. Annual blue shark catch in numbers by 10 fleets in the North Pacific. Acronyms in the "Fleet Key" are defined in Table 1.

Table 6. Definitions of fleets used in the Multifan-CL analysis.

Fleet	Acronym
Drift Net, Small Mesh ("Squid Net")	DN SM
Drift Net, Large Mesh	DN LM
Hawai'i Longline, targeting Swordfish, operating north of 25°N	HLL SN
Hawai'i Longline, targeting Swordfish, operating south of 25°N	HLL SS
Hawai'i Longline, targeting Tuna, operating north of 25°N	HLL TN
Hawai'i Longline targeting Swordfish, operating south of 25°N	HLL TS
Japan Longline, shallow sets, operating north of 25°N	JLL SN
Japan Longline, shallow sets, operating south of 25°N	JLL SS
Japan Longline, deep sets, operating north of 25°N	JLL DN
Japan Longline, deep sets, operating south of 25°N	JLL DS

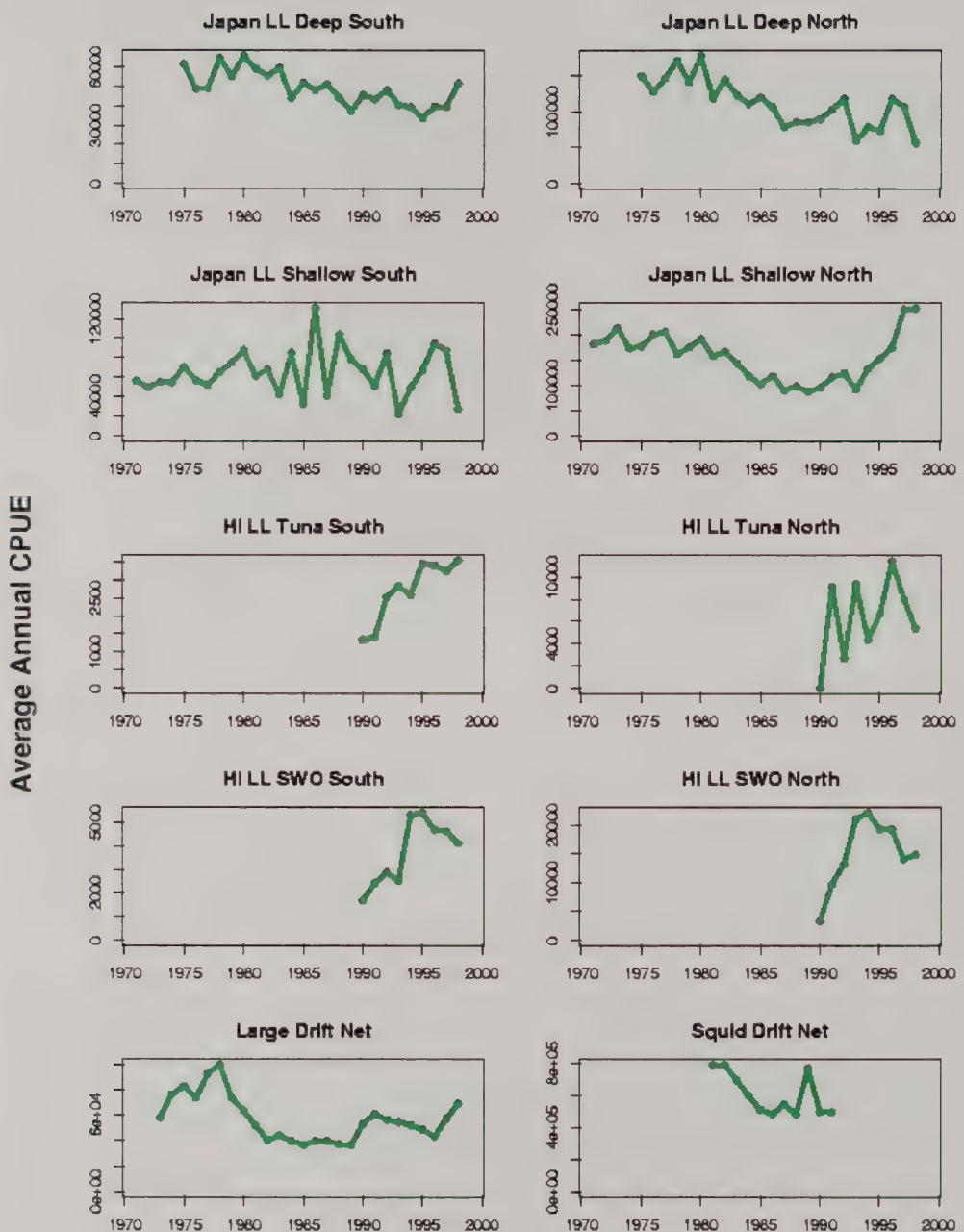

Figure 13. Average annual catch per effort by 10 fleets in the North Pacific.

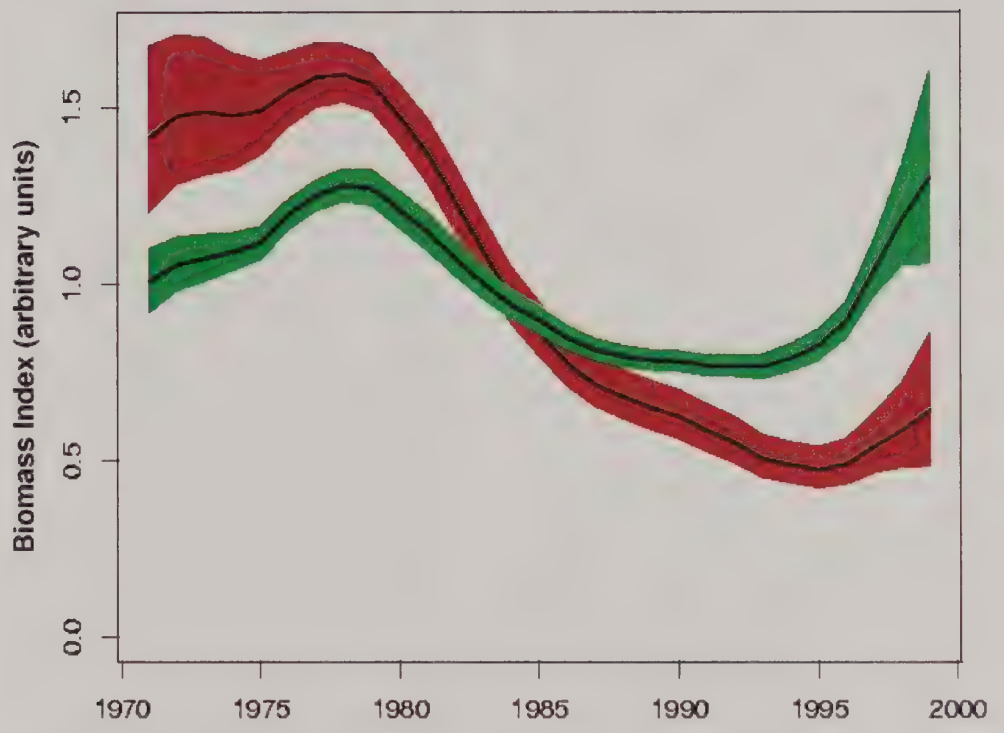

Figure 14. Multifan-CL estimates of relative blue shark biomass for two different regimes of variation in catchability. Red–wide variation in catchability allowed; Green–variation in catchability strictly limited. Colored regions indicate approximate 95% confidence bands.

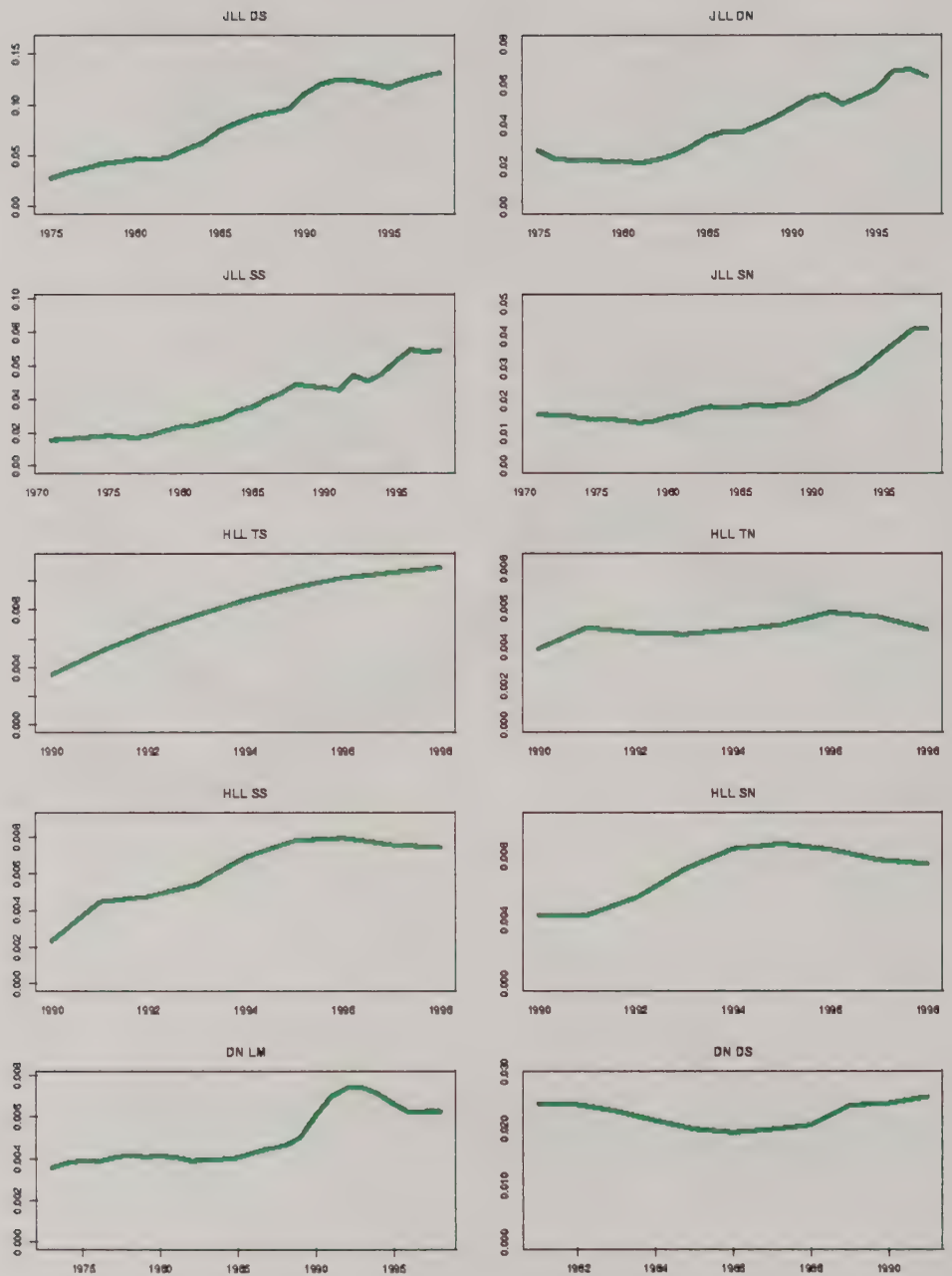

Figure 15. Trends in catchability in ten fleets in the North Pacific estimated by Multifan-CL in scenario with large variation in catchability allowed. Acronyms in the "Fleet Key" are defined in Table 1.

Modeling Activities

Relatively little is known about the status of swordfish stock (*Xiphias gladius*) in the North Pacific, and substantial uncertainty and incompleteness characterize the associated fishery statistics. During 1998-99, an operational simulation model was designed at HL to evaluate the performance of stock assessment procedures in this data poor context (Fig. 16). This type of model is basically an amalgamation of data, parameter estimates, and hypotheses from various sources that best represent the fishery as we know it. The current version of the swordfish simulation model is based on the results of morphometric studies; tracking and tagging operations; stock assessments of Atlantic swordfish (by the International Commission for the Conservation of Atlantic tunas [ICCAT]) and Pacific swordfish (by NMFS and ICCAT); and oceanographic and ecological investigations. It incorporates key features of aged-structured and length-based models and can account for growth, reproduction, mortality, recruitment, exploitation, and movement. The latest version of the model can project trends in abundance; catch and stock composition; recruitment patterns; spawning biomass; and so forth for multiple stocks and fleets, under user-specified levels of process and observation error, sampling regimes, and exploitation patterns. When supplied with the existing time series of fishing effort for the major North Pacific fisheries, the model predicts catch trends that conform well to the observed patterns over 1952-96 (Fig. 17).

The operational model was recently used to test the performance of a modified Pella-Tomlinson, nonequilibrium production model. Time series of catch and effort data were generated from the simulation and then used as input to the production model analysis. The accuracy of the estimates of production model parameters was determined by comparing them to the known values used to generate the data under simulated but realistic conditions concerning stock productivity, exploitation patterns, sampling constraints, and observation errors. The production model was found to perform well under some fairly complex conditions, with the parameter estimates generally within 35% of their known values. However, the estimates were unreliable when the spatial coverage of the fishery expanded with time, when the catch-effort time series lacked contrast, and when various combinations of measurement errors contaminated the data series.

The operational model was also used to gain provisional insight into the productive capacity of the North Pacific swordfish population. The potential long-term yields associated with different hypothetical levels of exploitation were simulated over 150-year periods, assuming the 1996 fishing effort distribution was constant during the last 100 years of the simulation. The results indicate that the fishing mortality coefficient in 1996 was about 0.025, when total yield was about 16,000 t. The simulated maximum long-term annual yield (LTY) was 57,000 metric tons (t), or about 3.5 times greater than the yield in 1996. At the maximum yield level, the fishing mortality coefficient is about 0.26, which corresponds roughly to the hypothesized mean annual natural mortality coefficient for males and females. An LTY of 57,000 t, while speculative, is considered plausible, and exceeds the peak North Pacific swordfish catch in 1960 of about 38,000 t. These preliminary simulation results are characterized by considerable uncertainty. Still, the results are not inconsistent with the results of the production model analysis, which despite its shortcomings, suggested that the swordfish population has been subject to relatively low exploitation rates. Current plans are to revise and improve the stock assessment and conduct further evaluations as new information becomes available.

Key components of the operational swordfish simulation model are currently being modified to conduct a similar investigation on the North Pacific blue shark (*Prionace glauca*) population. Biological and fishery data were recently obtained for this purpose. The data are being used to re-parameterize the model and provide the background information needed to conduct various numerical

simulations and generate simulated data under a range of biological and operational assumptions. These will help gain further insight into the productive capacity of this population and will complement the ongoing stock assessment investigation of blue shark using MULTIFAN-CL.

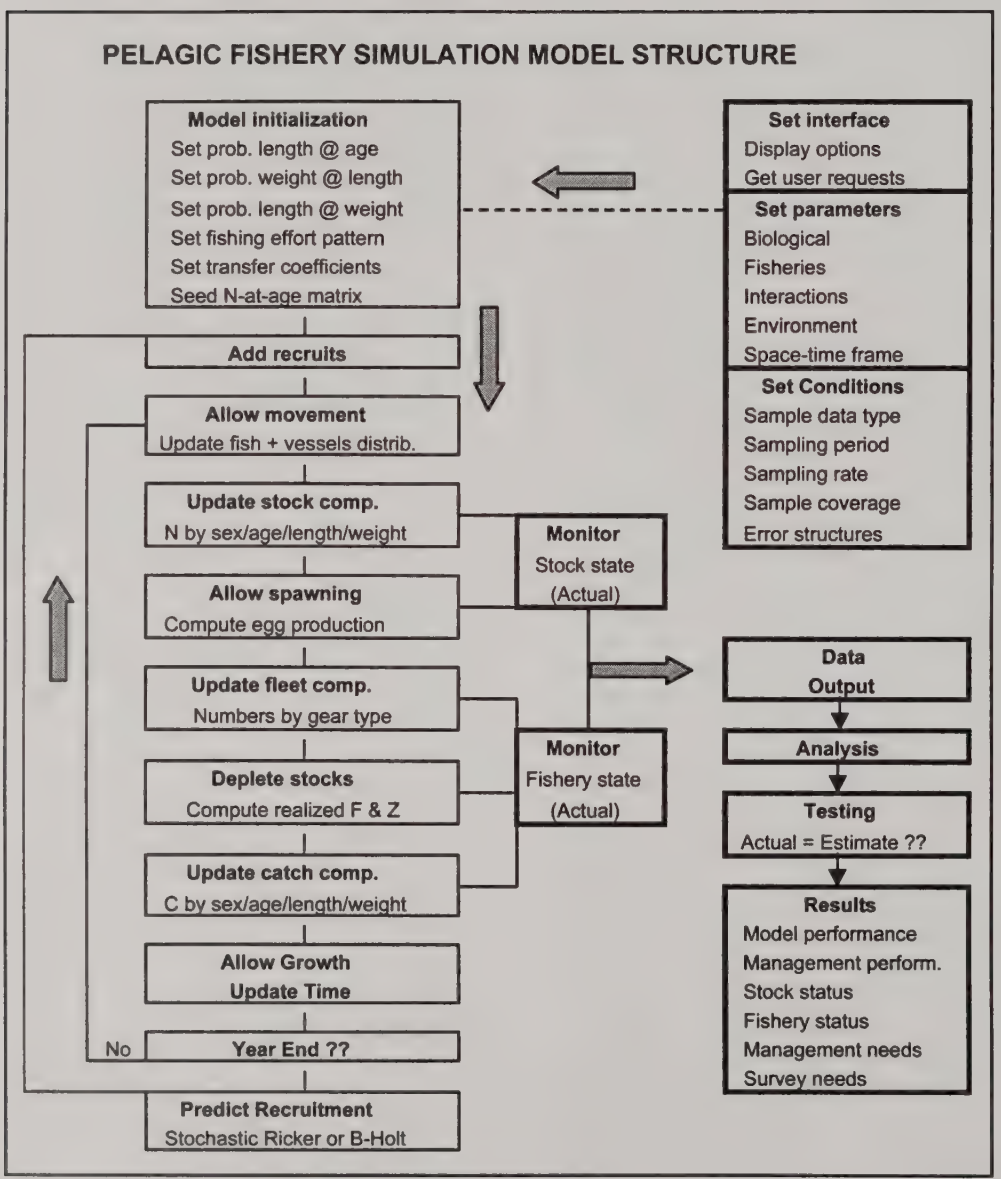

Figure 16. Operational model structure and principal components.

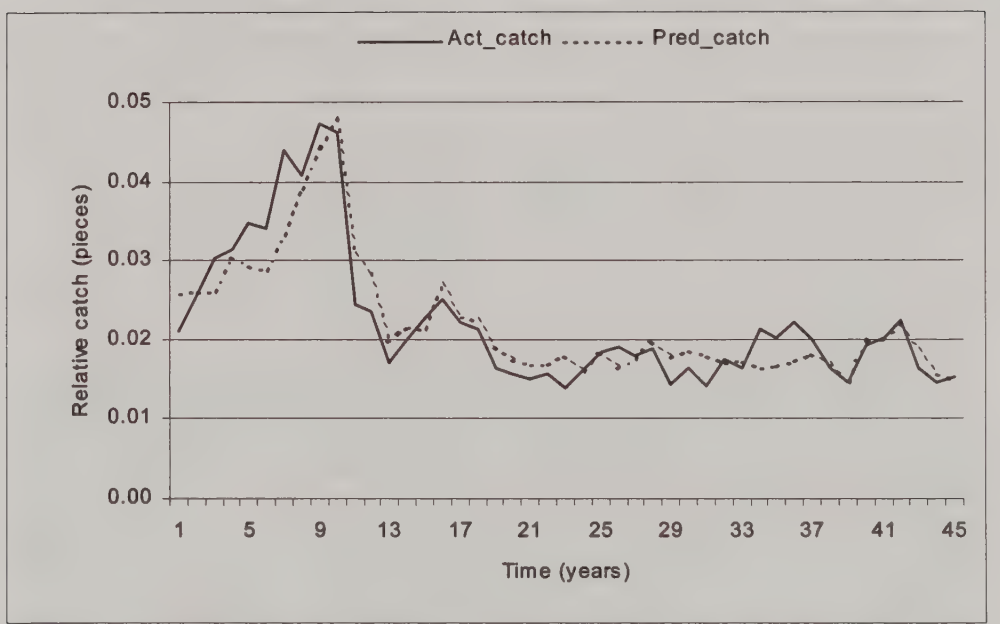

Figure 17. Actual and predicted catch levels based on Japanese and US longline fishing effort only over 1952-1996.

Coordination with Pacific Fishery Management Council and NMFS Headquarters on Highly Migratory Species Management

Substantial efforts are being made at HL to coordinate scientific advice to the Southwest Region/Pacific Islands Area Office (SWR/PIAO), the Fishery Management Councils, and international organizations on the management of fisheries for tunas, billfishes, sharks, and other highly migratory species (HMS). The Western Pacific Regional Fishery Management Council (WPRFMC) is working on revisions to a partially approved amendment to its Pelagic Fishery Management Plan (FMP), and the Pacific Fishery Management Council (PFMC) is developing a new management plan for HMS. Since the stocks of pelagic fish range far beyond the jurisdictions of regional domestic management authorities, there is a need to coordinate NMFS input to various developing fishery management instruments. A meeting to discuss pelagic fishery management issues was held in La Jolla in March with representatives from NMFS Headquarters, Southwest Fisheries Science Center SWFSC, SWR, HL, and PIAO. In April the PFMC HMS Plan Development Team meeting was held as a video conference with participation by the HL scientist who chairs the WPRFMC Pelagic Plan Team. Reciprocal participation by NMFS scientists chairing and advising the WPRFMC and PFMC teams on pelagic HMS is continuing as the two councils work to complete FMPs and Amendments required by the Sustainable Fisheries Act (SFA).

One very important SFA requirement faced by both councils and the NMFS Sustainable Fisheries Office (SFO) is the definition of overfishing and establishment of control rules to monitor and control fishing intensity and stock biomass (Fig. 18). In May HL completed an Administrative Report containing recommendations on these matters. The document was modeled after the recently approved Atlantic FMP for Atlantic tunas, swordfish, and sharks. The report suggests that overfishing is occurring on the

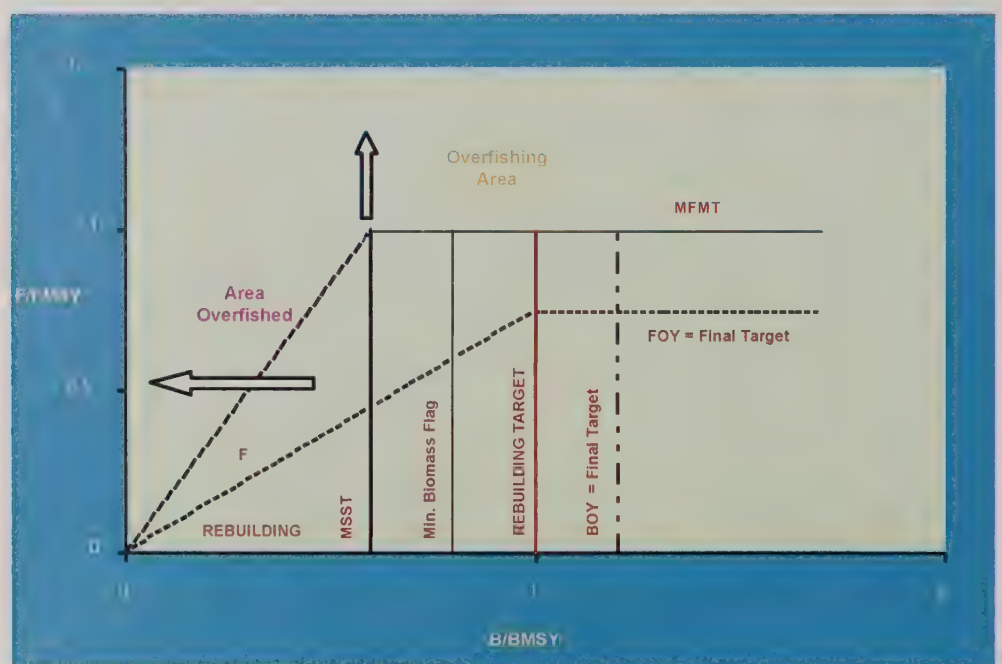

Figure 18. Maximum Sustainable Yield (MSY) and Optimal Yield (OY) control rules for regulating fishing effort (F) and maintaining biomass (B) at desirable levels in relation to two reference points: (1) the Maximum Fishing Mortality Threshold (MFMT) and the Minimum Stock Size Threshold (MSST).

Pacific-wide stock of bigeye tuna and on yellowfin tuna in the eastern Pacific, but the report also finds that the biomass of these stocks has not yet declined to an overfished status. Action recommended by the plan includes continuing to limit fishing effort in the U.S. domestic longline fishery for tuna and swordfish and petitioning for international agreements to reduce fishing effort on bigeye tuna throughout the Pacific. In the eastern Pacific, the Inter-American Tropical Tuna Commission (IATTC) has a management plan in effect to reduce and control fishing effort on yellowfin tuna. The report points out that such international management efforts are essential for management of the stocks because of the tiny fraction of fishing mortality by fisheries that are controlled by WPRFMC authority (Fig. 19).

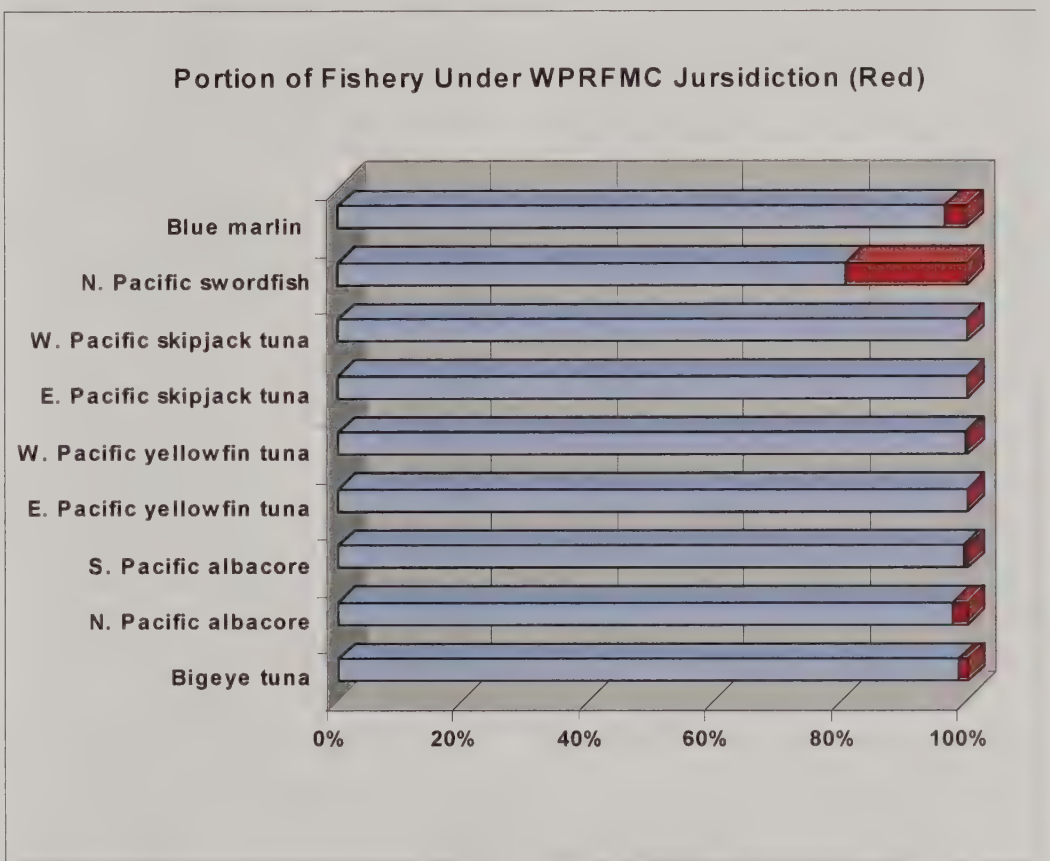

Figure 19. Fractions of fishing mortality on stocks of Pelagic Fishery Management Unit Species caused by fisheries under WPRFMC jurisdiction.

Interactions of the Hawaii-Based Longline Fishery with Sea Turtles and Seabirds

Background Information

Since 1994 there has been an observer program operated by the SWR for the Hawaii-based longline fishery. The observer program places trained observers on randomly selected longline trips. During these observed trips, the number of turtle and albatross takes by species and the condition of the animal, other species of concern, and possible explanatory variables are recorded by the observer. A take is defined as an interaction between an animal and the fishing vessel or gear. A turtle take usually implies that a turtle was entangled in the line or was caught on a hook. Most of the sea turtles are released alive but affected to an unknown degree by injury and trauma induced by their capture. Almost all of the seabirds are dead when the longline is retrieved. Mortality resulting from the incidental capture in longline gear is a cause of concern because the affected populations are classified as endangered or threatened under the Endangered Species Act or protected by other statutes. Under a NMFS Biological Opinion (BO) concerning the longline fishery, NMFS is required to monitor allowed levels of incidental take and kill of sea turtles and to seek ways to reduce them. Other requirements apply to incidental mortality of seabirds.

Goals and Objectives

- To estimate seabird and sea turtle takes and mortalities in the longline fishery.
- To identify factors that are associated with take rates of sea turtles and seabirds.
- To improve statistical methodology for modeling and estimation of takes.
- To conduct seabird deterrent research.
- To provide scientific advice for litigation related to fishing interactions with protected species.

Major Accomplishments and Research Activities

Interactions with Sea Turtles–The HL has continued to improve the statistical methodology for analyses of the interactions of the Hawaii-based longline fishery with sea turtles. A primary objective is to estimate the numbers of turtles taken and killed annually in the fishery. Results are provided to SWR, which monitors the incidental take and mortality in relation to levels authorized for each species under the BO for the fishery. The SWR issues an annual report of take and mortality levels and other results of the observer program.

To estimate total take, prediction models were developed using 1994-99 observer data. Separate models were developed for each species. These prediction models were then applied to the unobserved sets to predict their takes. The point estimate for total take was the sum of predicted takes for unobserved sets added to the take from observed sets. The total turtle mortality caused by longline interactions was estimated for each species by multiplying the estimated total take by average kills per take, the latter calculated from observer data and other information. Estimates of post-release survival are expected to be improved as results emerge from the NMFS program to monitor the movements and behavior of turtles hooked and released with sophisticated satellite transmitters.

This year more rigorous modeling techniques have been deployed to develop the prediction model. These techniques took into account the rarity of a turtle take, and as a result, the power to detect variables associated with take was increased. To measure the uncertainty in the point estimates, prediction intervals were approximated using bootstrap methodology, which was also used to estimate the probabilities that actual takes and kills exceeded levels allowed under the current BO Incidental Take Statement.

Explanatory variables included in the prediction model are given in Table 7. Results

are shown graphically in Figures 20 and 21. The point estimates of olive ridley mortality for 1995-99 were above the authorized take level for this species stipulated in the current Biological Opinion. Out of 32 observed olive ridley takes, 6 have been reported as dead with 3 of them in 1998 and 1 in 1999. As a result, the estimated probability of olive ridley takes that die as a result of interacting with the fisheries is 33% versus 17% for loggerhead turtles, 13% for green turtles, and 8% for leatherback turtles. Take estimates for olive ridley are below the authorized level for 1998 and 1999, although the estimated probability that the take exceeded the level was 46% for 1999. From 1995 to 1999, the estimates for kill and take of olive ridley turtles appear stable with only the slightest indication of an upward trend.

Take and mortality point estimates for leatherback, loggerhead, and green turtles were below the authorized take level for 1998 and 1999. The probabilities that the total take for loggerhead and leatherback turtles exceeded the authorized mortality are below 1%; for the green turtle, the estimated probabilities are 28% and 34% for 1998 and 1999, respectively. The increased number of estimated leatherback takes in 1998 and 1999 can be explained numerically by the increased percentage of trips below latitude 14.95°N. From 1994 to 1997, there were 2,186 sets and in 1999, 1,758 sets. The probabilities that total mortality exceeded the authorized mortality are below 1% for the green and loggerhead turtles, and below 25% for the leatherback turtle. In almost all cases, point estimates of take or kill fell clearly within the prediction intervals for earlier and later years; thus, there is no evidence of a trend.

In addition to estimating turtle takes, the modeling techniques used for developing a prediction model will be used to determine what factors are associated with take.

Table 7. Explanatory variables included in the prediction models

Species	Explanatory variables
Loggerhead	month in three categories: [1,2], [5,6], [3,4,7-12] latitude as a polynomial: latitude + latitude^2 sea surface temperature in two categories: [sst≤23.77°C], [sst>23.77°C]
Olive Ridley	sea surface temperature in two categories: [sst≤24.22°C], [sst>24.22°C]
Leatherback	latitude in four categories: [lat≤14.95 °N], [14.95°N ≤lat ≤24.84°N], [24.84°N<lat≤33.82°N], [lat >33.82°N]
Green	none

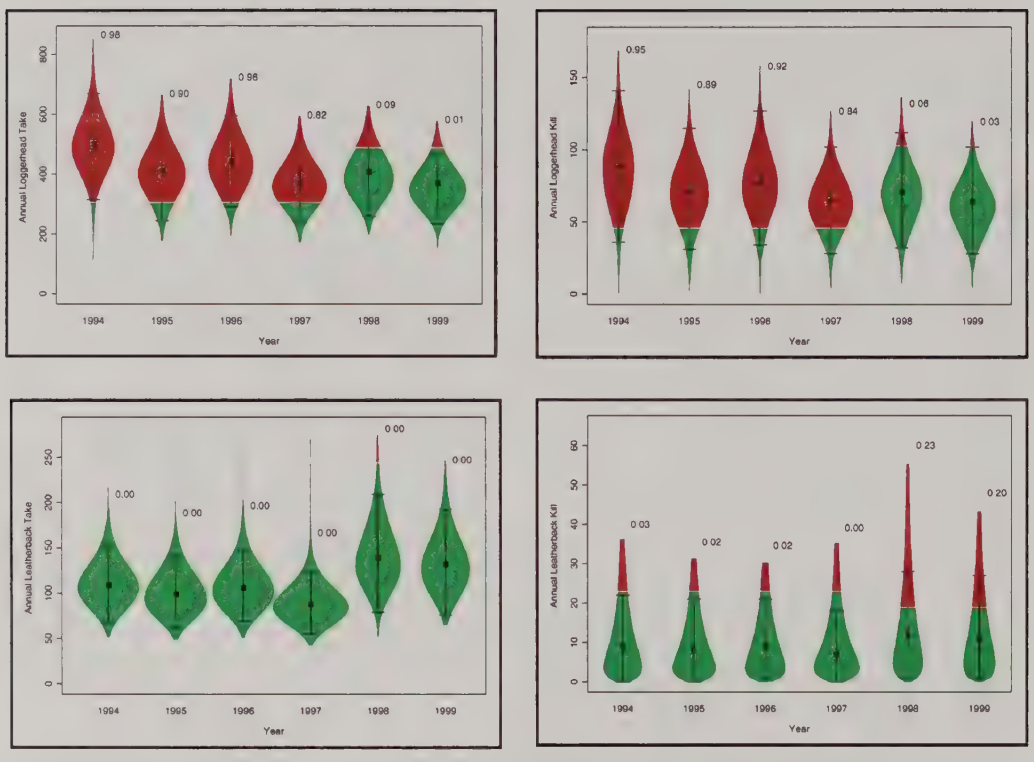

Figure 20. Take and mortality estimates for loggerhead and leatherback turtles. Point estimates and approximate 95% prediction limits are superimposed on the transformed studentized bootstrap distribution. The red portion of the plot is the approximate portion of the distribution above the allowed level. Estimated probabilities that the allowed level is exceeded appears above each distribution.

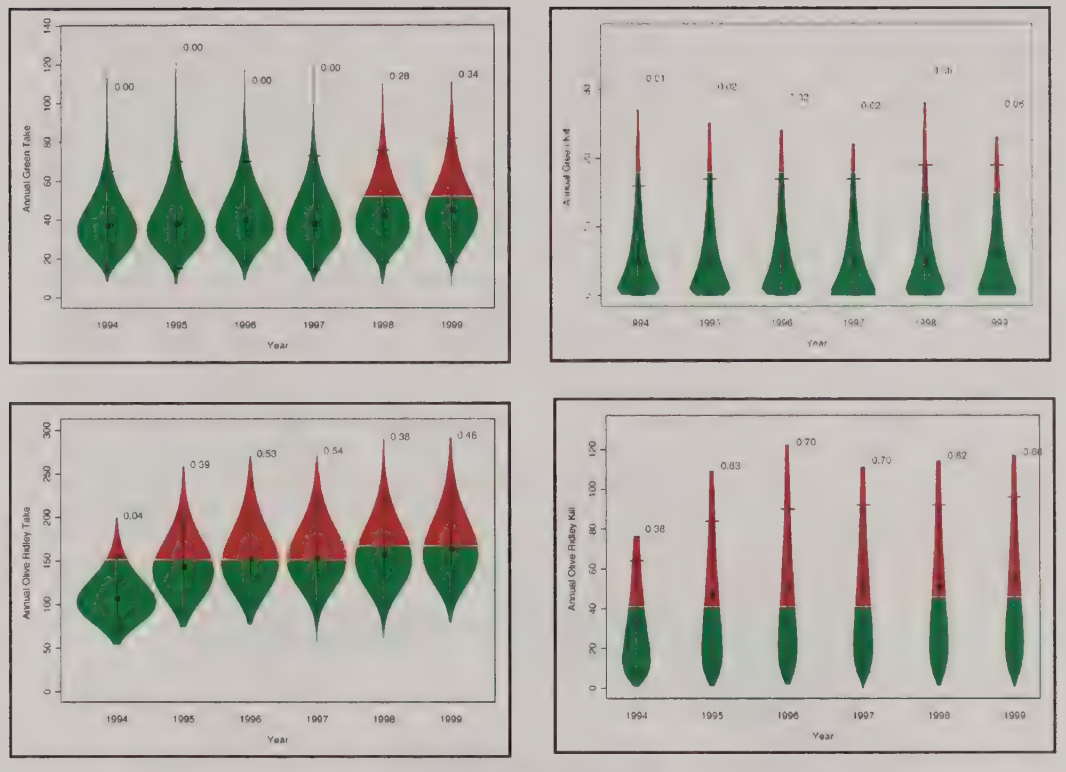

Figure 21. Take and mortality estimates for green and ridley turtles. Point estimates and approximate 95% prediction limits are superimposed on the transformed studentized bootstrap distribution. The red portion of the plot is the approximate portion of the distribution above the allowed level. Estimated probabilities the allowed level is exceeded is written above each distribution.

Time/Area Closure Analysis for Turtle Take Reductions

In response to the *Center for Marine Conservation (CMC) et al.* v. *NMFS et al.* lawsuit (CIVIL NO. 99-00152), time/area closures of the Hawaii-based longline fishery were examined at the Honolulu Laboratory (HL) using computer simulation to identify management scenarios that would effectively reduce interactions with sea turtles while minimizing hardship to longline fishermen. Figures 22a and 22b indicates the locations of the court-ordered closures and of the longline fishing grounds. As a first step, generalized additive models (GAMs) were used to construct a database of predicted turtle take for each set of longline gear over the time period 1994-98. The GAMs were estimated from detailed observations gathered by NMFS-SWR observers and high-resolution environmental data merged with the fishery data. Computer simulation was used to assess the impact of seasonal (monthly resolution) closures or spatial (whole degrees of latitude/longitude resolution) closures over a systematic grid of 361,194 possible closure scenarios. Leatherback turtles were of primary concern due to their endangered status. Immediate impacts to the fishery were measured by predicting the fraction of the fleet displaced spatially or temporally by the proposed management action. Financial impacts were also estimated using predicted catch rates of the displaced fishing effort and recent market revenue data. "Efficient frontier" analysis was used to determine the efficacy of proposed management scenarios. This approach is used primarily in Modern Portfolio Theory, but has wide applicability for the identification of optimal solutions in a complex setting. The solid red line in Figure 23 is a polynomial representation of the efficient frontier for leatherback turtle take with respect to the amount of fishing effort displaced by the management action. Due to the widespread patterns of leatherback turtle take (primarily in space, but also in time), it was difficult to determine an optimal management scenario. The results of these analyses, summarized in a report but also with ancillary information, were provided to a panel of experts (meeting in Honolulu March 29-31, 2000) representing the plaintiffs, the longline fishing industry, and NMFS. The expert panel submitted their independent recommendations to NMFS the following week. Based on these recommendations and heuristic approaches, NMFS Headquarters proposed a split-season, multi-area closure on April 21,2000 to replace the emergency closure currently in place.

On August 4, 2000, the court ordered three area closures (Fig. 22b), each with different conditions, that will remain in effect until a new Environmental Impact Statement (EIS) is prepared for the fishery. The court ordered the EIS to be completed by April 2001.

22a

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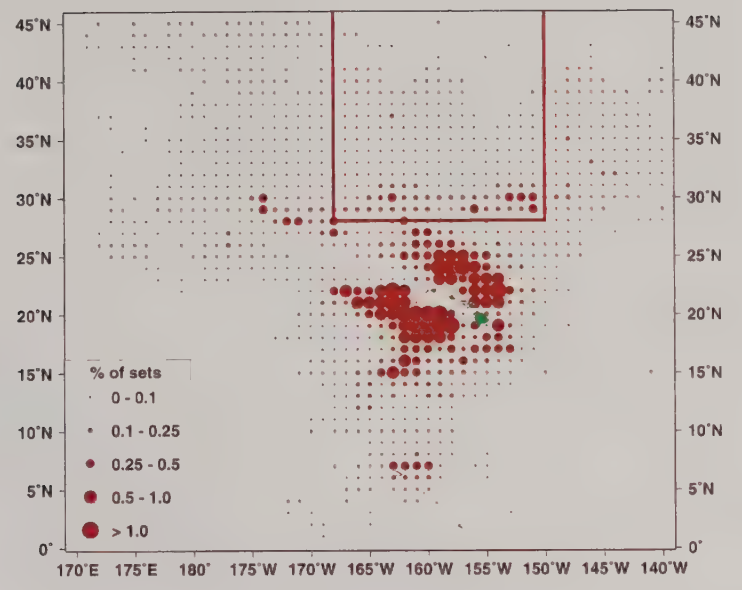

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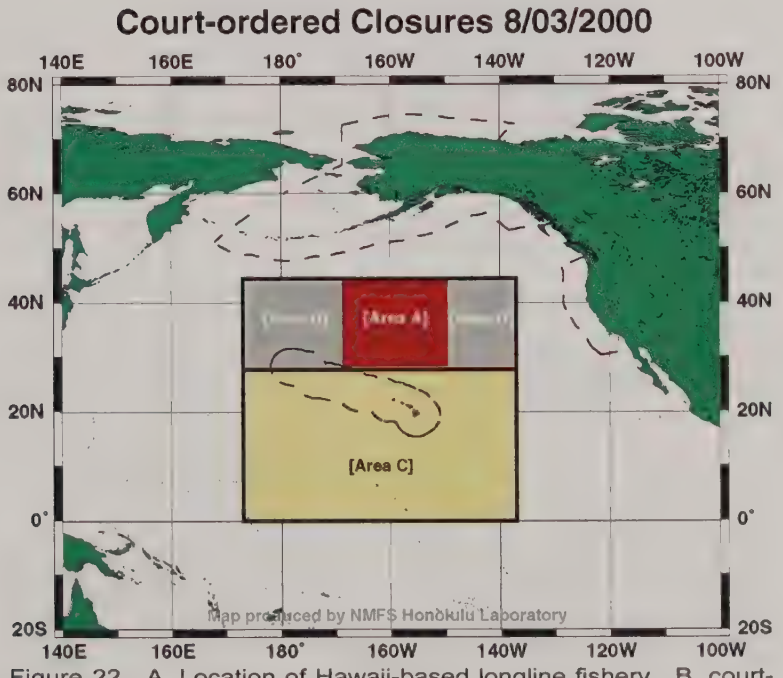

Figure 22. A. Location of Hawaii-based longline fishery. B. court-ordered Closure.

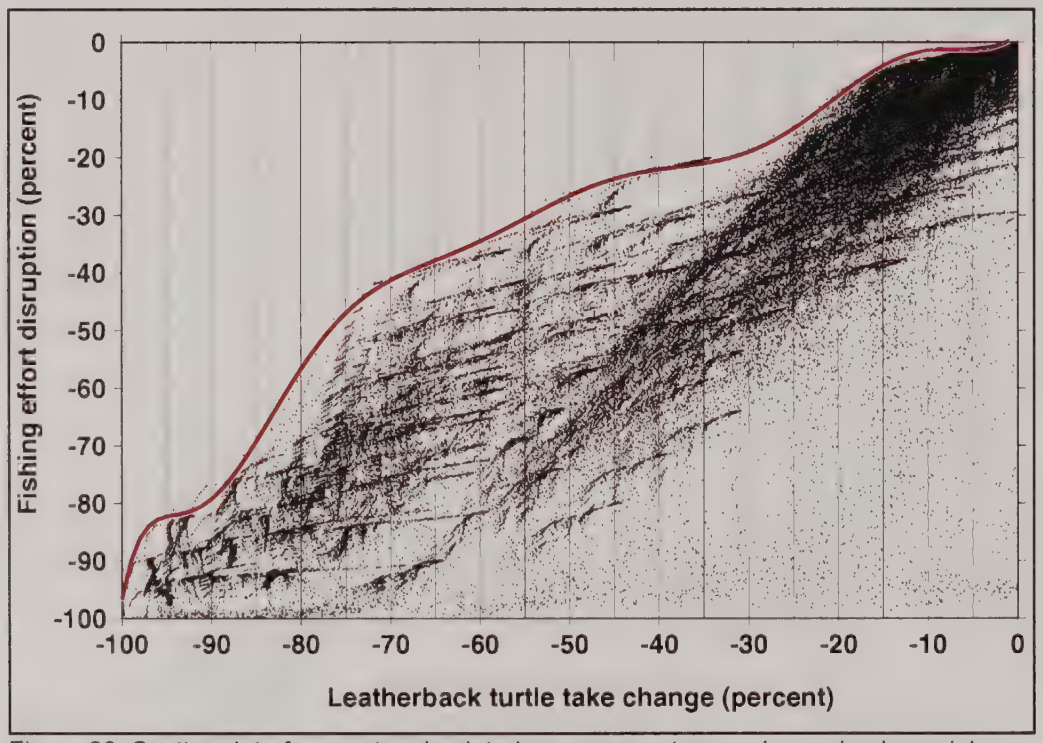

Figure 23. Scatter plot of computer simulated management scenarios and polynomial representation of the "efficient frontier".

Additional Research on Fishery Interactions with Sea Turtles

In addition to the development of statistical models to estimate sea turtle takes and mortalities resulting from longline fishery interactions, HL is conducting important research and other activities to understand and mitigate fisheries interactions with sea turtles. This includes the following:

- Investigation of sea turtle post-hooking survival and oceanic habitat (discussed in section on Pacific Sea Turtle Research and Recovery).
- Coordination of workshops with sea turtle experts, veterinarians, and fishermen to address methods to reduce fishery interactions and to safely handle sea turtles incidentally caught in fishing operations.
- Analysis of factors associated with longline fishery interactions with sea turtles based on NMFS observer records (discussed in section on Pacific Sea Turtle Research and Recovery).
- Development of sea turtle population simulation model (TURTSIM).
- In collaboration with scientists from HL at SWFSC in La Jolla on genetic studies to determine the population origin of sea turtles caught incidentally in the Hawaii longline fishery.

Additional research has been recently initiated to:

- Investigate the seasonal movement dynamics of leatherback sea turtles.
- Evaluation of artificial bait to reduce the incidence of longline hooking of sea turtles.
- Refinement and application of the (TURTSIM) model to the longline fishery interaction issue.
- Further analysis of factors associated with longline fishery interactions with sea turtles.

Investigation of seasonal movement dynamics of leatherback sea turtles–This investigation will utilize information on:

- Leatherback sea turtle residence times and foraging and diving patterns measured by electronic archival data tags.
- Information on ocean currents, sea surface temperatures, and oceanic productivity derived from data collected simultaneously by orbiting satellites.
- Data on sea turtle takes from NMFS observer records.
- Data on fishing effort from longline logbook records.

These data will be combined in a coherent GIS analysis of longline fishing effort, leatherback turtle distributions in relation to oceanographic conditions, and turtle interactions per unit of longline effort to identify times and areas where closures could effectively reduce fishery interactions with leatherback sea turtle; as well as other sea turtle interactions, to rates deemed acceptable but that are also minimally disruptive to the fishery.

The electronic archival data tags to be used in this study will be capable of being jettisoned from the turtles on a predetermined schedule. Information on turtle swimming depth and daily record of geolocation and sea surface temperature will be transmitted ashore by ARGOS satellites. These tags, called pop-up satellite tags (PSATs), will be attached to leatherback turtles using safe biocompatible methods similar to those proven successful for deployment of PSATs on large pelagic fishes. Attachment techniques will be tested using captive animals and turtles on nesting beaches in Mexico and possibly Malaysia or Indonesia. Some animals will also be outfitted with conventional satellite tracking instruments for ground-

truthing positions derived from the PSATs. Attachment of PSATs to turtles on nesting beaches will allow the collection of data from animals that have not been hooked by longline fishing gear. For animals entangled or hooked by longline gear, hook location will be recorded photographically. The severity of injury and the general state of the turtle will be scored based on a standardized scale prior to release.

Blood samples and tissue biopsies will be collected from animals equipped with PSATs for molecular/biochemical studies to quantify fitness and rates of mortality following release. According to NMFS observer records, few sea turtles hooked in the Hawaii-based longline fishery are dead when brought aboard or alongside a vessel. The survival of released turtles has, however, been difficult to ascertain. Moreover, excluding injuries due to direct hook penetration, delayed mortality of sea turtles may also occur following release from longline gear not only as a direct result of immediate metabolic perturbations but also as a result of irreversible cellular damage. An understanding of the long-term post-release morbidity and mortality is fundamental to the formulation of effective management policies. This research will develop molecular and clinical approaches that will allow a better understanding of the extent and nature of tissue damage resulting from interactions with longline gear, including the following:

- Measurement of "stress proteins" or "heat shock proteins" that can be correlated with delayed mortality.
- Development of methods, based on standard clinical practices, to assess the extent of specific organ damage occurring in released turtles.
- Assessment of the extent of delayed anemia.

Evaluation of artificial bait to reduce the incidence of longline hooking of sea turtles–Investigators in Alaska have successfully developed an artificial bait that sharks avoid, but this bait does not lower catch rates of halibut and black cod by bottom longline gear. This finding offers hope that it may be possible to use artificial bait that is not only offensive or unattractive to sea turtles but will also maintain catch rates of targeted species. Tests will be conducted to determine if the existing artificial bait shown to reduce shark bycatch in the Alaskan bottom longline fishery may be effective with sea turtles. However, this is believed to be unlikely, and a more systematic approach will be followed. This will include studying sea turtle sensory physiology necessary to develop artificial bait that is undetectable or repulsive to turtles. To this end, olfactory capabilities of captive turtles will be conducted at HL's Kewalo Research Facility (KRF) and NMFS laboratories on the mainland using standard electrophysiological and behavioral techniques. Based on the outcome of these findings, artificial baits will be prepared and tested for avoidance by captive sea turtles. Following this, artificial baits will be tested at sea for their efficacy at catching tunas and swordfish, using either cooperating commercial fishermen or directed research longline cruises.

Refinement and application of sea turtle population simulator (TURTSIM)–A prototype sea turtle population simulator, TURTSIM, has been developed to provide important provisional insights into the relative impacts of various human activities, including Hawaii-based longline fishing, on recovery of sea turtle populations. Analyses of this sort can provide guidance on comparative effects of various human activities and estimation of maximum net per-capita rates of population increase conditional on assumed scenarios of human activity, thus proving helpful in designing procedures to set allowable incidental take levels for fisheries.

A second type of analysis not yet supported in the TURTSIM prototype is the assessment of biological risks associated with human impact scenarios or management interventions including uncertainties arising from inherent natural variability in turtle population dynamics and observations of turtle

abundance. To enable such risk analyses, TURTSIM will be modified to incorporate biological process stochasticity (e.g., variability in growth, mortality, maturation, hatchling production, and remigration) and observation errors (e.g., annual survey estimates of nester abundance or levels of human-caused mortality). The TURTSIM prototype will also be modified to allow greater flexibility in specifying population structure (defining life-stages) and regulatory mechanisms (density dependence), and incorporating ancillary data on the abiotic factors that may affect vital rates of turtles (e.g., catastrophic events like severe storms, or shifts in oceanographic conditions). Additionally, we intend to incorporate tuning of the models by fitting estimated nester abundance to historical nesting survey observations. To the extent possible we intend to evaluate the relative contribution of principal human activities toward the decline of these turtle populations and the recovery gains expected to result from reducing each source of mortality.

Through collaboration with sea turtle biologists working in other countries (e.g., Mexico, Malaysia, and Japan) the biological database upon which the simulator is based will also be updated and improved. The goal is to provide the best biological foundation for TURTSIM models and the most authoritative estimates of nesting counts and mortality caused by local human activities on the nesting beaches and in adjacent waters.

Analysis of factors associated with longline fishery interactions with sea turtles–An analysis of the observer data to identify explanatory variables; e.g., sea surface temperature, light sticks, moon phase, depth of fishing, etc., associated with takes of leatherback as well as loggerhead and olive ridley turtles will be undertaken. The objective of this research is to determine if possible changes in longline fishing tactics and operations can reduce interactions with sea turtles. Because of the hierarchical data structure, the rarity of the observed takes, and the likelihood of overdispersion, there are many challenges regarding the appropriate statistical methodology to be used in this study. Several possibilities will be considered and assessed, and new statistical methodology will be developed as needed.

Seabird Deterrent Research and Management Measures

Research on seabird deterrent methods was conducted in 1999, culminating in a set of recommended measures to reduce seabird takes by modifying fishing operations. In the Hawaii-based fishery, a swordfish longline is typically set in the late afternoon or evening and is fished during the night. During a set, albatrosses may attack the baited branch lines as they are tossed out behind the vessel (Fig. 24) until they sink beyond reach.

Figure 24. A tori line is like a scarecrow. It is dangled from a pole to stream over the baits behind the vessel.

Albatross cannot dive or swim very deep, so once the baits have sunk a few meters underwater the birds are not vulnerable to being caught. Fishermen around the world have problems losing bait to albatrosses, and they have developed a variety of methods to keep birds away. Japanese fishermen developed the bird-scaring "tori" line, which is a rope with fluttering streamers towed from a high point or pole mounted over the stern of a fishing vessel. The streamers dangle in the air over the baits, repelling the birds until the baits sink beyond reach. Hawaii fishermen have also successfully used bait dyed deep blue with food coloring so that it becomes hard for the birds to see it. (Fig. 25) Adding weight to fishing gear near each baited hook to speed up the sinking rate can also keep the bait away from birds. In the Hawaii-based swordfish fishery the branch lines are already

Figure 25. Dyeing the squid bait dark blue, using food coloring, makes the bait much harder for the albatross to see.

weighted but adding more weight near the hook could reduce interactions with seabirds. A more common method used by Hawaii fishermen is to wait until after dark to set the line.

The Honolulu Laboratory's (HL) seabird deterrent research project tested a tori line, weighted bait, and blue-dyed bait for their efficacy in deterring black-footed and Laysan albatrosses from contacting baits deployed by the Hawaii-based longline fishery. A rigorous statistical design for the study was developed based on seabird interaction data collected by NMFS fishery observers. The NOAA ship *Townsend Cromwell* was used to set longline gear in daylight near a major albatross colony in the NWHI, which greatly increased the number of bird interactions with the gear and the power of the statistical analysis. No birds were actually hooked during the NMFS research cruise because large safety pins (net pins) were used instead of hooks (Fig. 26). Albatross contacts with baits were observed in 96 test sections deployed during 24 longline sets. With about 70 hooks deployed per test section; the test sections lasted about 20 minutes. Equal numbers of test sections were observed with no treatment (control), with the tori line, with blue bait, and with weighted bait.

Results of the study showed that all three methods greatly reduced the number of times albatross came in contact with longline baits (Fig. 27). Blue-dyed bait and weighted bait each reduced the number of times birds

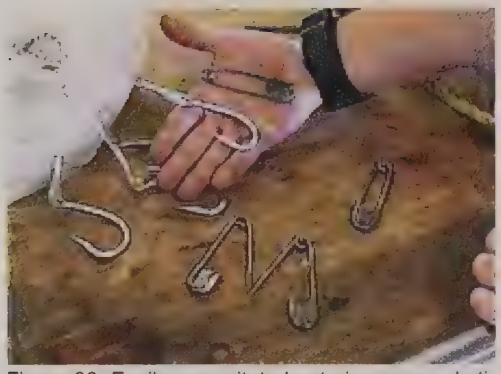

Figure 26. Easily regurgitated net pins were substituted for hooks in the research to reduce injury to the albatross.

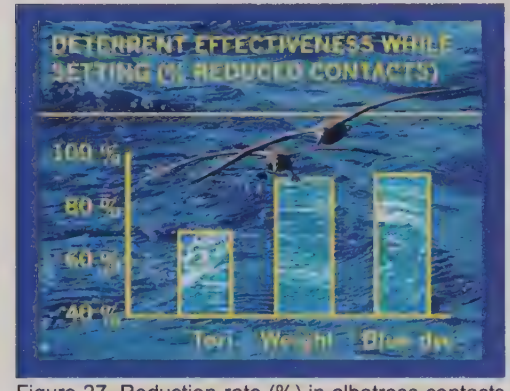

Figure 27. Reduction rate (%) in albatross contacts with bait in comparison to control treatments.

contacted baits by about 90% during setting. The tori line reduced bird contact with baits by about 70% during setting. Albatross are most often killed by longlines during setting because if these birds are hooked or entangled they sink with the gear and are drowned, whereas if they are hooked during the haulback they can be released. Boobies, shearwaters, frigate birds, terns, and petrels were observed during the study but not one of these other taxa ever contacted the baited lines, only albtrosses. No short-tailed albatross were seen during the hundreds of hours spent observing thousands of birds. Of the North Pacific albatrosses, short-tailed albatross have the smallest population. Although they are seldom found in the Hawaiian Archipelago, one was reported to have been sighted during one research cruise and one by a fishery observer in the range of the Hawaii-based fishery.

Of the albatrosses actually taken in the Hawaii-based fishery, black-footed albatross have the smallest population and are most vulnerable to longline hooking. Black-footed albatross plumage changes with age. Less than one-year-old birds have uniformly dark-brown plumage. After their first year they acquire white-tipped tail coverts (Fig. 28). Old birds may reach 40 years in age. In the study, when albatross approached the vessel close-

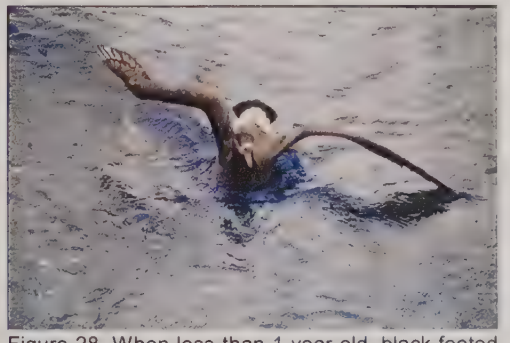

Figure 28. When less than 1 year old, black-footed albatross do not have white feathers near the tail as seen in this older bird.

ly during haulback, NMFS scientists recorded that more than half of the black-footed albatross had juvenile plumage, and that about 80% of the black-footed albatross that took baits off the lines were these young birds (Fig. 29). This result supports the idea that fishery-related mortality represents mostly young, inexperienced birds.

A paper on this research is in press. The deterrent methods tested in the study have been adopted as part of the management measures proposed by the Western Pacific Research Fishery Management Council. Further research, including both field testing and analyses of logbook data may help resolve which are the most effective deterrent methods. New methods are still evolving. Underwater line setters may provide a superior means of deterring birds from

taking bait, and these will be tested in the Hawaii fishery this year.

Estimating Numbers of Albatrosses Accidentally Caught During Hawaii Longline Fishing Operations.

In addition to conducting studies on methods for reducing longline fishing interactions with albatrosses, HL has been investigating methodology for making estimates of accidental catches of albatross during the Hawaii longline fishing operations. As with sea turtles, albatrosses have been estimated with regression tree models using data from NMFS observers and longline fishery logbook records. Estimates of annual incidental takes for both species using regression tree models along with bootstrap confidence bounds are given in Table 8 for 1994-98. Similar estimates for 1999 are in preparation.

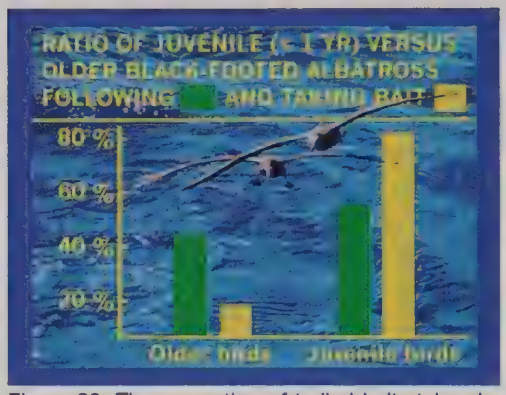

Figure 29. The proportion of trailed baits taken by young albatross is much higher than the proportion of young birds following the ship.

Table 8. Estimates of annual incidental takes of albatrosses in the Hawaii longline fishery and 95% confidence bounds. Annual takes recorded by NMFS observers on monitored fishing trips also given.

Year	Blackfooted Albatross		Laysan Albatross	
	Observed take	Total take Estimate [95% CB]	Observed take	Total take Estimate [95% CB]
1994	126	1994 [1508-2578]	73	1828 [933-2984]
1995	105	1979 [1439-2497]	107	1457 [767-2308]
1996	59	1568 [1158-1976]	31	1047 [569-1610]
1997	107	1653 [1243-2102]	66	1150 [599-1875]
1998	46	1963 [1479-2470]	56	1479 [822-2336]

INSULAR FISHERIES

The Honolulu Laboratory (HL) is responsible for providing scientific research and support for three insular fisheries in the Northwestern Hawaiian Islands (NWHI) insular lobster, bottomfish, and precious corals.

Lobster Fishery

Background

The NWHI commercial lobster trap fishery commenced in 1977 and primarily harvests two species: spiny lobster (*Panulirus marginatus*) (Fig. 30) and slipper lobster (*Scyllarides squammosus*) (Fig. 31). Two other species, green spiny lobster (*P. Penicillatus*) and ridgeback slipper lobster (*S. Haanii*), are caught in small amounts. The lobster trap fishery is managed under the FMP for the Crustacean Fishery of the Western Pacific Region.

Figure 30. Spiny lobster. Photo by Bruce Mundy.

Figure 31. Slipper lobster. Photo by Bruce Mundy.

Goals and Objectives of the NMFS Honolulu Laboratory Lobster Program

The HL has been conducting research on NWHI lobster stocks since the 1970s.The goals of the lobster research program are to provide scientific information in support of the Crustaceans FMP and management decisions that will ensure the long-term sustainability of lobster stocks in the NWHI. To achieve these goals, a comprehensive lobster research plan was developed and implemented. The plan should be considered a working document, subject to revision as necessitated by ongoing research and management developments. Objectives of HL's lobster research plan include the following:

- Monitor and assess the status of lobster stocks in the NWHI.
- Acquire understanding of fleet economics and dynamics.
- Investigate biology, ecology, and essential fish habitat requirements as recommended by HL's Lobster Research Team (LRT).

Major Research Activities

To support the research goals and objectives of the lobster research program the HL conducts a suite of multidisciplinary research activities. The activities outlined below refer only to stock assessment activities. Information on studies related to lobster essential fish habitat is found in a later section.

Assess Status of Lobster Populations in the NWHI–Recent improvements in the understanding of the spatial structure of NWHI lobster populations, the dynamics of larval transport, and the commercial fishery have identified shortcomings in existing NWHI lobster stock assessment models. Most of the shortcomings stem from uncertainties about biological processes and life history characteristics, resulting in increasing levels of uncertainty in estimating the exploitable population of NWHI lobsters. To address the shortcomings, species-specific models to

estimate exploitable population size that incorporate fishery-dependent, fishery-independent, and environmental data at appropriate spatial scales are being developed.

In addition, HL will continue to conduct annual fishery-independent research cruises and fishery-dependent monitoring programs to collect population dynamics and relative abundance data to assess the status of lobster stocks in the NWHI. The research cruises and monitoring programs also provide a platform for conducting experiments recommended by HL's LRT.

Reestimation of Biological and Population Parameters for Spiny Lobster in the NWHI–During a recent technical review of the NWHI lobster stock assessment models, it was recommended that research programs be developed to provide fishery-independent estimates of population size and updated estimates of population dynamics parameters for both spiny and slipper lobsters. This information is required to advance the development of species-specific models and facilitate model verification analyses. HL's LRT has determined that collaborative tagging experiments and biological sampling should be implemented to provide the necessary data.

A spiny lobster tagging experiment designed to provide updated estimates of growth, movement, abundance, and survival was developed and implemented at Necker Island in 1998. The 1999 NWHI commercial lobster fishery provided the platform for recaptures, and a rigorous analysis of the 1999 recapture data is underway. Additional spiny lobster tagging at Necker Island is proposed for the year 2000, as well as the expansion of a spiny lobster tagging experiment to Gardner Pinnacles. Slipper lobster tagging experiments at Maro Reef are expected to commence in 2001 after an effective tag has been identified

Efforts are underway to evaluate size at sexual maturity and fecundity for slipper lobster in the NWHI. This work is critical as only spiny lobster life history parameters are available to use as input to NWHI lobster stock assessment models despite the growing importance of slipper lobster to the commercial fishery.

A pending lawsuit to exclude all fishing activities (commercial and research) in the NWHI could seriously jeopardize scientific research efforts to improve lobster management. This is especially true for the ongoing tagging project, as well as newly planned tagging experiments. This research is essential to improve lobster population models and to advance the understanding of (1) lobster spatial distribution and life histories and (2) possible relationships between lobster and monk seals.

Issue Estimates of the Exploitable Population of Lobsters in the NWHI–Spatial management of the NWHI lobster trap fishery commenced in 1998 with the formation of four management areas–Necker Island, Maro Reef, Gardner Pinnacles, and all remaining banks. This approach was adopted in an effort to prevent local depletion of lobster stocks at Necker Island, Maro Reef, and Gardner Pinnacles and to spread out fishing effort in the NWHI, which in recent years has been limited to Necker Island and Maro Reef. To facilitate spatial management during the fishing season, estimates of the exploitable population of lobsters on July 1 (start of the fishing season) in the four management areas are required. HL will continue to provide these estimates using the guidelines provided by the Crustaceans FMP.

Status Determination Criteria and Control Rules–The Magnuson-Stevens Fishery Conservation and Management Act (MSFCMA) contains a set of 10 National Standards for fishery conservation and management. National Standard 1 (Optimum Yield; OY) of the MSFCMA states, "In general, Councils should adopt a precautionary approach to specification of OY." A common element in the application of the precautionary approach to fisheries management is the definition of status determination criteria or biological reference points and control rules. A control rule is a pre-agreed plan for

making fishery management decisions (i.e., reduce fishing mortality) based on estimates of stock size relative to a defined set of status determination criteria (i.e., maximum sustainable yield; MSY). HL estimated several biological reference points, including some which were defined as overfishing status determination criteria under the MSFCMA. These reference points were incorporated into MSY and YOY control rules and offered as suggestions for consideration by the WPRFMC (Fig. 32).

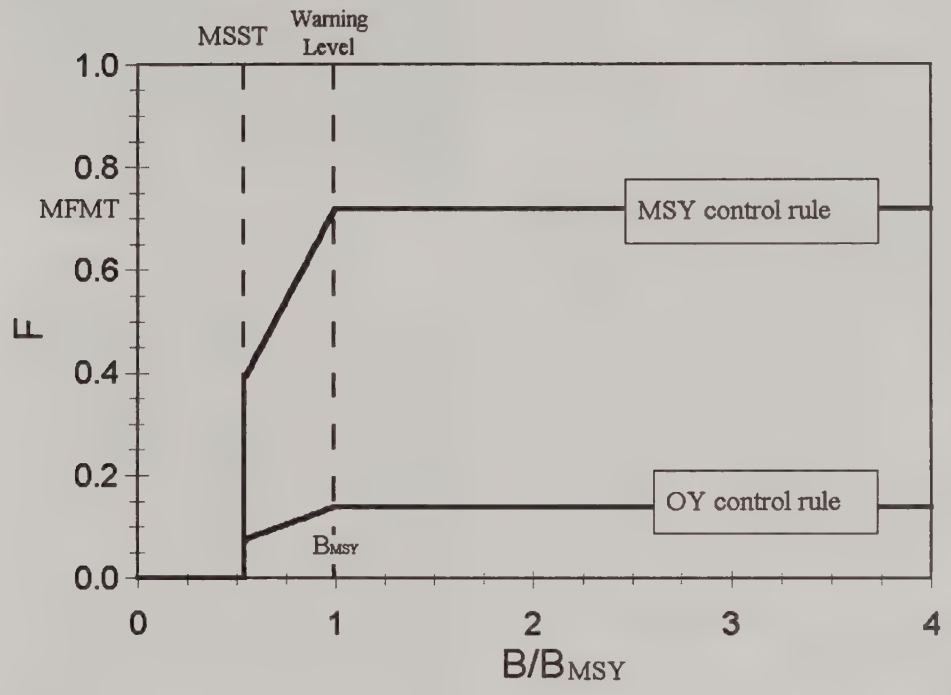

Figure 32. Proposed MSY and YOY control rules for the NWHI lobster fishery (MFMT = maximum fishing mortality threshold, MSST = minimum stock size threshold, B = biomass, Bmsy = spawning biomass corresponding to MSY, F = fishing mortality).

BOTTOMFISH FISHERIES

Background

The bottomfish fishery in the Hawaiian Archipelago in a multispecies, deepwater (100-400 m) fishery operating primarily from small (5-20 m) boats. Fishermen use baited handlines with electric or hydraulic powered reels. The primary species are four eteline snappers (onaga, *Etelis coruscans*; ehu, *Etelis carbunculus*; opakapaka, *Pristipomoides filamentosus*; uku, *Aprion virescens*) and a grouper (hapuupuu, *Epinephelus quernus*), which together account for approximately 78% of the total bottomfish landings by weight. Several other species of snappers and jacks make up the remainder of bottomfish landings. The Northwestern Hawaiian Islands (NWHI) is a federally managed fishery split into two fishing zones--the Hoomalu zone (French Frigate Shoals to Hancock Seamount) and the Mau zone (Nihoa to Necker)–both of which are limited-entry fisheries at present. The main Hawaiian Islands (MHI) are primarily under State of Hawaii jurisdiction.

Nonlethal Assessment Techniques in Bottomfish Refuges

Honolulu Laboratory (HL) scientists are involved in a cooperative study with the Hawaii Division of Aquatic Resources (HDAR), Hawaii Institute of Marine Biology (HIMB), and the U.S. Fish and Wildlife Service Cooperative Fisheries Unit using the Hawaii Undersea Research Laboratory (HURL) submersible *Pisces V*. Dives in 1999 revisited sites off eastern Oahu and Penguin Banks surveying areas within bottomfish marine protected areas (MPAs) and adjacent open fishing areas. This was the second year of dives conducted at these sites refining nonlethal assessment techniques, evaluating habitat and faunal community associations, and developing a baseline abundance estimate for monitoring anticipated increases in snapper population densities with continued closure of newly established MPAs. The 1999 dives observed greater numbers of juvenile and subadult ehu and onaga than were observed in the 1998 dives at the same sites. Transects and bait stations were conducted on all dives. Figure 33 shows a bait station with ehu, *Etelis carbunculus*, yellowtail kalekale, *Pristipomoides auricilla*, and a large *Octopus sp.* The orange ball is a 12-inch diameter buoy used as a size reference. The octopus recognized the buoy as one of its own and took an instant liking to it, giving the buoy a big hug (Fig. 34). We also observed alfonsin, *Beryx decadactylus*, on several occasions during these dives (Fig. 35). At one location off eastern Oahu, over 30 individuals were observed under an overhang at 300 m on a limestone slope.

Figure 33. Ehu, yellowtail kalekale and an octopus at a bait station.

Figure 34. Octopus gives the 12-inch diameter reference buoy a hug.

Figure 35. Alfonsin observed from PISCES V submersible.

Sustainable Fisheries Act Overfishing Definitions

Changes are needed in the Bottomfish and Seamount Groundfish Fisheries Management Plan (BSGFMP) to bring the spawning potential ratio-based overfishing definitions into compliance with the Maximum Fishing Mortality Threshold (MSY)-based definitions required with the National Standard 1 of the Magnuson-Stevens Fishery Conservation and Management Act. HL scientists have proposed control rules based on default suggestions presented in the Technical Guidelines (Fig. 36). Under these rules overfishing occurs when fishing mortality (F) is above the level necessary to produce MSY, and stocks are overfished when biomass (B) falls below 0.70 of the biomass necessary to produce MSST (Minimum Stock Size Threshold). When B falls below MSST, a rebuilding plan is initiated that will bring B back to B_{MSY}. In order to prevent frequent overfishing events and to keep biomass well above B_{MSY}, a target is set for F at 75% of F_{MSY}. Keeping F at this target value (F_{OY}) will result in B increasing to 1.30 B_{MSY} and landings averaging about 95% of MSY. Assessment of stocks covered by the BSGFMP is based largely on commercial fisheries data collected by regional governments in Hawaii, American Samoa, Guam, and the Commonwealth of the Northern Mariana Islands and are restricted to catch and effort information. In the absence of annual estimates of F and B,

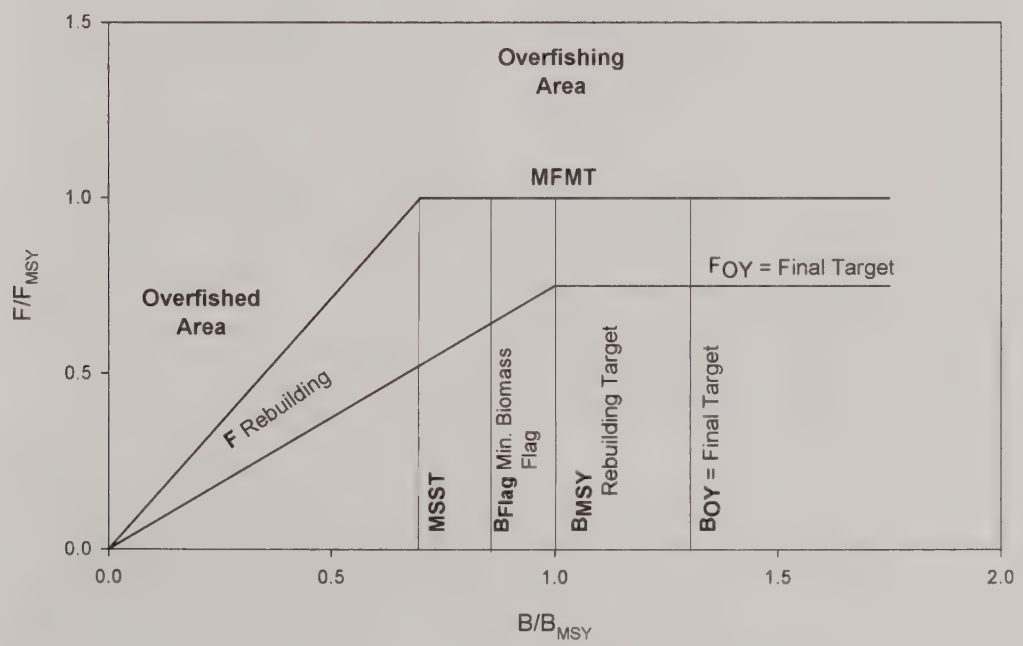

Figure 36. MSY Control Rule and Reference Points.

effort will proxy for F and CPUE effort will proxy for B. Reference levels for MSY and F_{MSY} will be calculated using the best information available. Since these reference levels are not currently available on a species-by-species basis, the stocks will be managed at a multispecies level until species level data is available.

Assess Population Status of Bottomfish

Bottomfish populations in the NWHI are presently considered to be healthy, based on assessments using commercial catch data and landed size distributions. Approximately 20% of bottomfishing grounds in the MHI are in Federal waters; however, the State of Hawaii has taken lead management jurisdiction in this region. Several MHI bottomfish populations appear to be locally overfished, and the State of Hawaii has recently initiated several management measures to alleviate this concern. The Western Pacific Regional Fishery Management Council (WPRFMC) has recently adopted an archipelago-wide stock assessment approach for bottomfish species in its jurisdiction. Results from this and from new methodologies resulting from compliance to Sustainable Fisheries Act and National Standard 1 are forthcoming.

HL scientists continue to analyze commercial fishery data to assess the status of bottomfish stocks in the Hawaiian Archipelago and summarize this information in the Hawaii module of the *Bottomfish and Seamount Groundfish Fisheries of the Western Pacific Region* annual report produced by the WPRFMC.

PRECIOUS CORALS FISHERY

Background

Hawaii's dormant precious coral fishery became active this year for the first time in decades. Last harvested in the late 1970s, corals growing at Makapuu, Oahu have recovered and have spurred new interest in coral harvesting. One company is currently harvesting the Makapuu bed using two submarines, and a second company is gearing up with similar technology. The Precious Coral management Plan (FMP) classifies coral beds into four categories–established, conditional, refuge, and exploratory. Established beds have a history of harvest with fixed optimal yields based on prior stock assessment of the site. Makapuu, Oahu is currently the only established bed in the FMP. Estimated yields from conditional beds are based on bed size, with the assumption that abundance and coral age structure are similar to those of Makapuu. There are currently four conditional beds and one additional bed which is designated as a refuge at which no harvest is permitted. Exploratory beds are those yet to be discovered, and these are divided into four regions: the Hawaiian Archipelago, Guam/ Commonwealth of the Northern Mariana Islands, American Samoa, and the U.S. Pacific Island Possessions. At the time of this program review, it is likely that the quota at the Makapuu bed will have been taken, and harvesters will be working on the quotas at other known grounds or searching for undiscovered beds.

Goals and Objectives

In support of the FMP, the Honolulu Laboratory's (HL) role is to research, monitor, and advise. Management is collaborative, drawing expertise from the University of Hawaii (UH), Hawaii Department of Land and Natural Resources (HDLNR), and private commercial coral businesses. Dr. Rick Grigg of the UH Department of Oceanography is an authority on deepwater corals and chairs the precious coral planning process which makes recommendations to the Western Pacific Regional Fishery Management Council (WPRFMC) and NMFS. A HL biologist serves as the primary NMFS representative on the planning team. The most recent amendment to the FMP banned nonselective harvest techniques (e.g., coral dredges) and increased reporting requirements for monitoring purposes.

Major Research Activities

Despite the fact that HL has no base funding allocated to address the precious coral fishery, attempts to find funding sources from outside NMFS continues. Collaborative work with National Geographic Television, grants from the Hawaii Underseas Research Laboratory (HURL) and the National Fish and Wildlife Foundation have afforded some limited research on the ecological role of deepwater corals. This preliminary research has identified three key concerns which require greater focus by HL. First, the growth rate and reproductive potential of some deepwater corals remain unknown. Second, deepwater corals, including both black coral and precious coral, may serve as essential habitat for commercially important bottomfish. Finally, endangered Hawaiian monk seals have been found to seek out beds of both precious (Fig. 37) and black corals as foraging habitat (Fig. 38). Future work will continue to draw on available expertise and leverage resources. HURL has awarded submarine time for work scheduled in Fall 2000, and a proposal for more submarine time in 2001 has been submitted. Additional proposals have been submitted to NMFS's essential fish habitat initiative and the U.S. Coral Reef Initiative for the prolonged funding necessary to address precious coral issues identified as important.

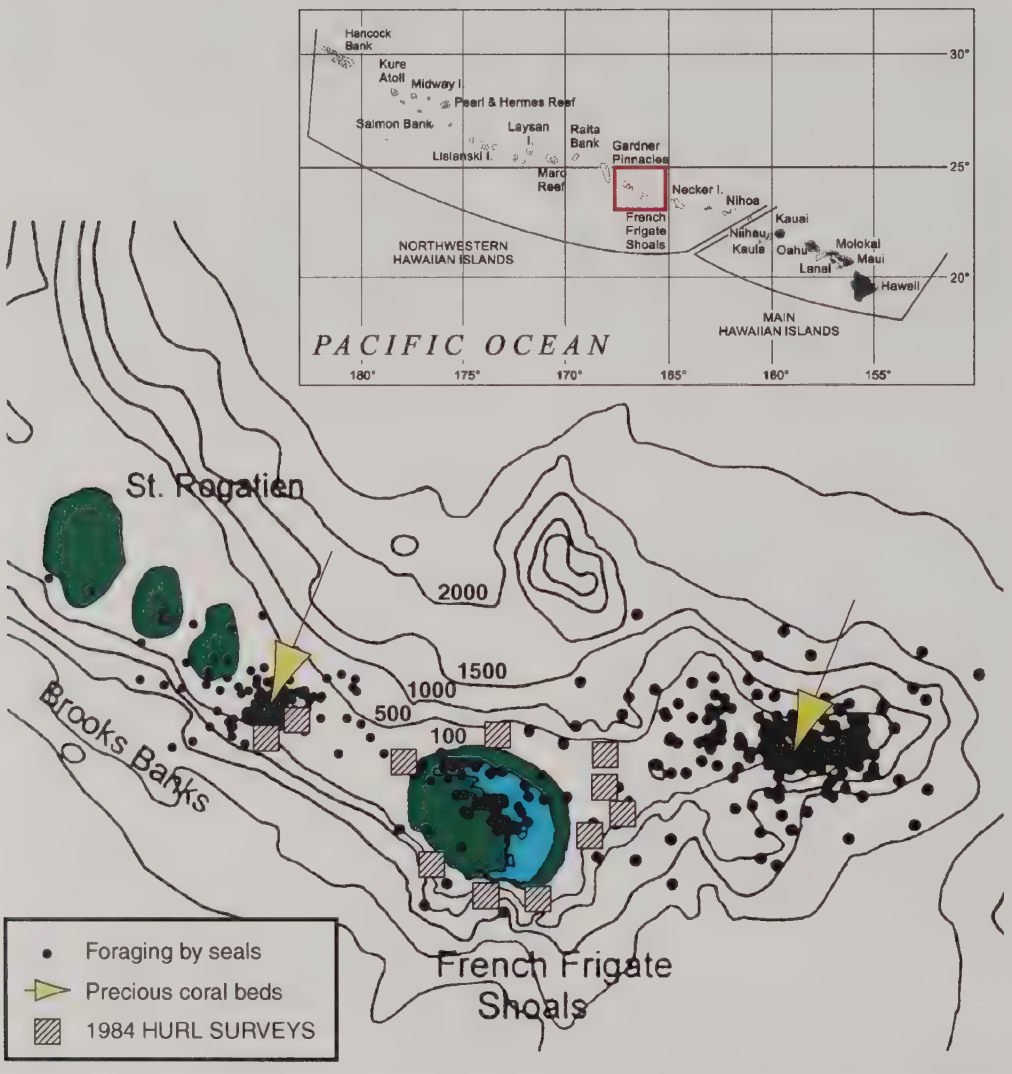

Figure 37. Map of the French Frigate Shoals region with black dots used to indicate satellite telemetry positions of the FFS seals that visited subphotic depths. The two arrows indicate where the 1998 submarine surveys found precious coral beds at the centers of seal foraging activities. The stripped squares surrounding FFS indicate earlier submarine surveys conducted in 1984, which found no coral beds. A map of the Hawaiian Archipelago is inset at the top with the FFS region highlighted.

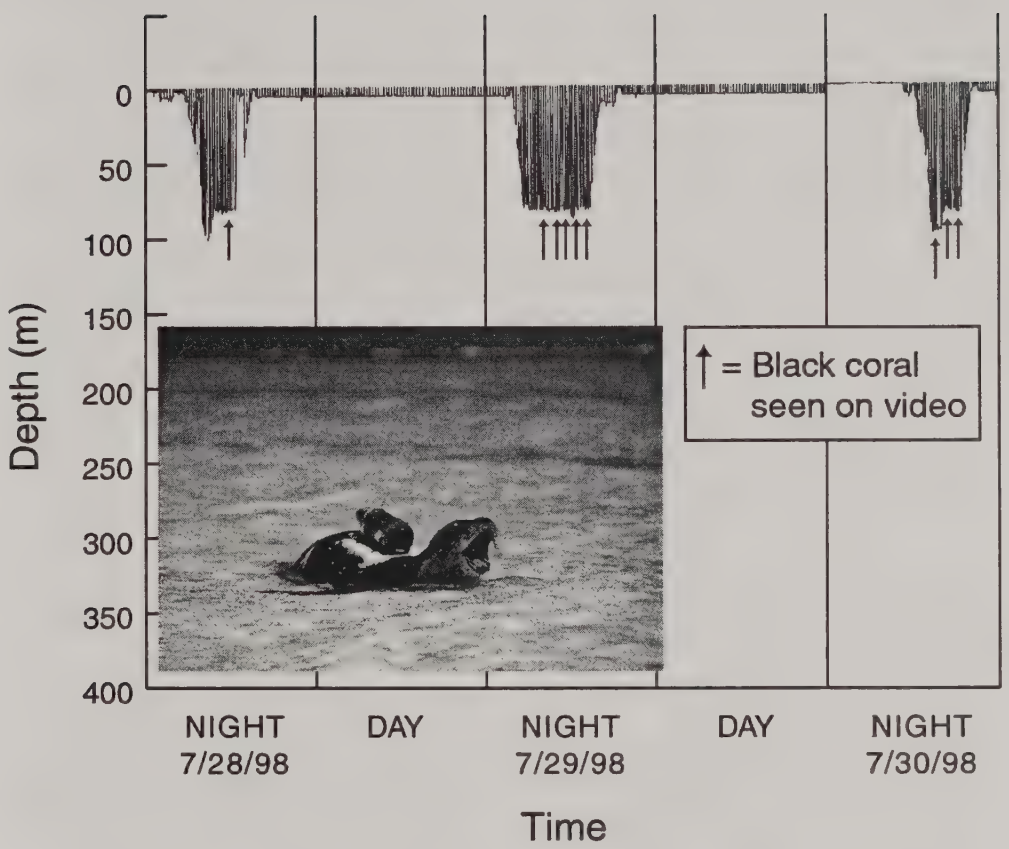

Figure 38. Dive profile of a FFS monk seal fitted with a night vision CRITTERCAM that indicates that the seal commuted between the atoll and the black coral bed on successive nights to feed. Arrows indicate where video sampling documented coral colonies. A photo of a monk seal fitted with a CRITTERCAM is inset at the bottom. Photo by M. Craig.

International Fisheries Management

Involvement in Scientific Activities Related to International Management of Highly Migratory Species

The Honolulu Laboratory (HL) has been assigned responsibility for providing scientific advice and information in support of U.S. interests in the emerging international management of highly migratory species (HMS) in the western and central Pacific. The framework for a Convention on the Conservation and Management of Highly Migratory Fish Stocks in the Western and Central Pacific is being developed by the Multilateral High-level Conference (MHLC). Several sessions of this conference have been held April 12-19, 2000 in Honolulu and the convention is expected to be completed and adopted at the 7th MHLC session planned in Honolulu during September 2000. HL has been given lead responsibility for NMFS scientific activities in support of U.S. participation in the convention.

HL has a long history of international cooperative research and data exchange. It is involved in numerous international scientific activities related to HMS data collection, data exchange, and stock assessment in the Pacific. Recently, international research by the HL has been focused particularly on swordfish, mostly under a work plan adopted by the Swordfish Working Group (SFWG) of the Interim Scientific Committee for Tuna and Tuna-Like Species in the North Pacific (ISC). The U.S. has leadership of this working group and is undertaking several cooperative research projects with other ISC partners in swordfish biology, oceanography, and stock assessment. In addition, HL is an active member of the ISC Statistics Working Group (SWG), has leadership of the ISC Marlin Working Group (not yet active), and provides statistics on albacore catches in the Hawaii longline fishery for North Pacific albacore stock assessments conducted in support of the ISC. In the South Pacific, HL is an active participant in annual meetings and activities of the Standing Committee on Tuna and Billfish (SCTB) of the Secretariat of the Pacific Community (SPC) and its various working groups.

All of these ISC and SCTB activities are important in providing scientific support on HMS issues pending the completion and adoption of multilateral arrangements under the MHLC. SCTB has been designated to serve as the interim scientific body to the MHLC convention upon adoption of the convention. Dr. Michael Laurs, Director of the Honolulu Laboratory, was named to an ad hoc steering committee to plan the transition from the present standing committee to the interim scientific body for the convention. Other members of the committee are Dr. Anthony Lewis, Director of the Pacific Community (SPC) Oceanic Fisheries Program; Dr. Ziro Suzuki, Outgoing Chairman of the SCTB, and Mr. Bernard Thoulag, Incoming Chairman of the SCTB.

A significant increase in funding and staff will be required for HL to meet the responsibilities that have been assigned to it regarding international management of HMS in the western and central Pacific.

International Data Exchange and Cooperative Research

In support of HMS stock assessment and related research, HL has entered into several agreements or arrangements for mutual exchange of fishery statistics and other data. These include several accords under the ISC and SCTB statistics working groups. HL also regularly provides statistics pertaining to Hawaii-based and U.S.-affiliated island pelagic fisheries to other HMS research organizations, e.g., the Inter-American Tropical Tuna Commission (IATTC) and SPC.

ISC and SCTB Statistics Working Groups–HL, La Jolla Laboratory, and NMFS Southwest Region Pacific Islands Area Office staff are participating on ISC SWG teams for

establishing data requirements and reporting protocols for pelagic fishery data to be provided to the ISC. The HL and La Jolla Laboratory staffs are collaborating on compiling west coast and Hawaii fishery statistics into a common package for delivery to the ISC. While a formal system for exchange of data is under development, fishery statistics have been exchanged for assessing swordfish and blue shark stocks.

HL became a participating member of the SCTB SWG in 1999. The SWG has concentrated its efforts on logbook forms and establishing minimum standards for collecting catch and effort statistics for fisheries operating on western Pacific HMS. Special attention is being paid to the need for particular data needs on fishing operations involving fish aggregating devices as well as improved information on bycatch, including protected species.

Collaborative Stock Assessment and Biological Research

HL has developed agreements for data exchange on a bilateral basis specifically to support joint stock assessment. The latter arrangements include collaborations between the HL and Japan National Research Institute for Far Seas Fisheries (NRIFSF) for stock assessments of swordfish, marlins, and North Pacific blue shark (results from the latter assessment are found in section on blue shark stock assessment). HL has also established collaborations with institutions in several countries to enable HMS research. In particular, HL staff are collaborating with swordfish scientists in Japan, Chile, and Taiwan (see section on swordfish for additional information). There is also an extensive cooperative research project between HL and NRIFSF on the biology and ecology of North Pacific blue shark, including a tagging project. In addition, cooperative research is also underway through the U.S.-Mexus Pacific Program with Mexican scientists on stock assessment of leatherback sea turtles and on fibropapillomatosis infecting Mexican sea turtles. HL also has extensive cooperative efforts with Australian fisheries scientists at the Commonwealth Scientific and Industrial Research Organization laboratory in Hobart, Tasmania on science related to HMS. Specific examples include development and testing of pop-up satellite archival tag technology and HMS stock assessment methods, and there are plans for collaboration on swordfish biology/ecology and fishery oceanography. There are also considerable interactions between scientists at HL and SPC related to stock assessments of HMS. In addition, HL is active in SPC SCTB research working groups including bigeye tuna and billfish and bycatch working groups. At the most recent meeting of the SCTB held in July 2000, HL scientists chaired a special session on fishery oceanography and delivered five presentations dealing with longline fishery bycatch, bigeye tuna oceanography, bigeye tuna archival tagging, Pacific basin-wide swordfish simulation modeling, North Pacific blue shark assessment, and an overview of swordfish research at HL.

Fishery Oceanography Applied to Marine Ecosystems and Essential Fish Habitat

Background Information

Interannual and decadal variation in stocks of marine fishes and populations of protected species results from natural fluctuations in the ocean environment and human-induced impacts including harvesting, habitat loss, pollution, etc. An understanding of the variation in the ocean environment, which may cause changes in the ecosystem, is necessary before it can be determined whether observed ecosystem variation is due to environmental change or human impact. Recent advances in satellite remote sensing and ocean circulation models have greatly increased our knowledge of ocean dynamics. Maintaining a strong collaboration with Hawaii CoastWatch, Honolulu Laboratory's (HL's) Fishery Oceanography programs have developed innovative approaches to using data from a number of satellite sensors including altimetry, ocean color, and governmental operational environmental satellite (GOES) sea surface temperature, together with data from research cruises, moorings, commercial fisheries, and satellite telemetry for investigating a wide range of physical-biological linkages in the central North Pacific.

Goals

The goals of HL fishery oceanography research are to advance knowledge of ocean and ecosystem dynamics with particular focus on the central Pacific pelagic ecosystem and the Northwestern Hawaiian Islands (NWHI) insular ecosystem.

CENTRAL PACIFIC PELAGIC ECOSYSTEMS MONITORING

HL has a long history in conducting ecological research on highly migratory species and on monitoring pelagic ecosystems in the central and western Pacific. Reported here are recent research activities related to the pelagic ecosystem dynamics of the North Pacific Transition Zone Chlorophyll Front (TZCF), highly migratory species oceanography featuring swordfish and bigeye tuna, and the application of ECOSIM simulation modeling to the central North Pacific pelagic ecosystem.

Transition Zone Chlorophyll Front

Pelagic ecosystem dynamics on all temporal scales may be driven by the dynamics of very specialized oceanic features. One such feature is the basin-wide chlorophyll front located at the boundary between the low and high chlorophyll subtropical gyres. Global satellite maps of surface chlorophyll clearly show this feature in all oceans. In the North Pacific, the front is over 8,000 km long and seasonally migrates north and south about 1,000 km (Fig. 39). In the winter it is located at about latitude 30°-35°N and in the summer at about 40°-45°N. Since this chlorophyll front moves seasonally between the southern and northern limits of the Transition Zone, TZCF. The TZCF represents a zone of surface convergence caused when cool, vertically mixed, high chlorophyll surface water on the north side sinks beneath warm, stratified, low chlorophyll water on the south. Satellite telemetry data on movements of loggerhead turtles, Laysan albatross, and detailed fisheries data for albacore tuna indicate that all these species forage at this front and in some cases travel along it as they migrate across the North Pacific (Fig. 40). The front is easily monitored with ocean color satellite remote sensing. Interannual variation in the position and strength of the TZCF has been observed and appears to have impacts on marine resources. For example the TZCF moved more northward between the first and second quarters in 1998, compared to 1997, and

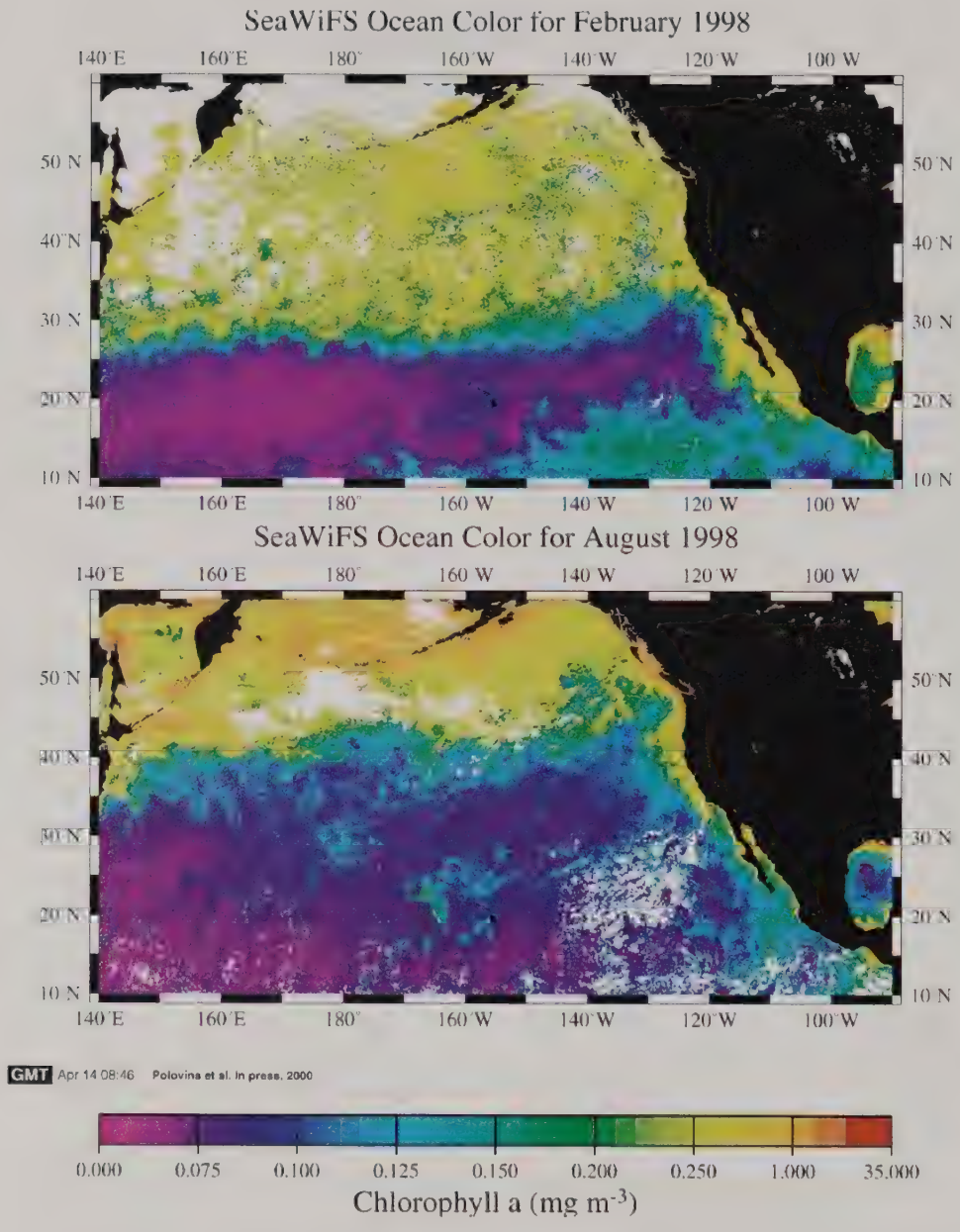

Figure 39. Mean surface chlorophyll for February and August 1998, with the red contour line marking the transition zone chlorophyll front as indexed by the 0.2 mg/m^3 chlorophyll level.

loggerhead turtles tracked in 1998 had a greater northward movement than those tracked in 1998 (Fig. 41). In the spring of 1999 surface chlorophyll levels in excess of

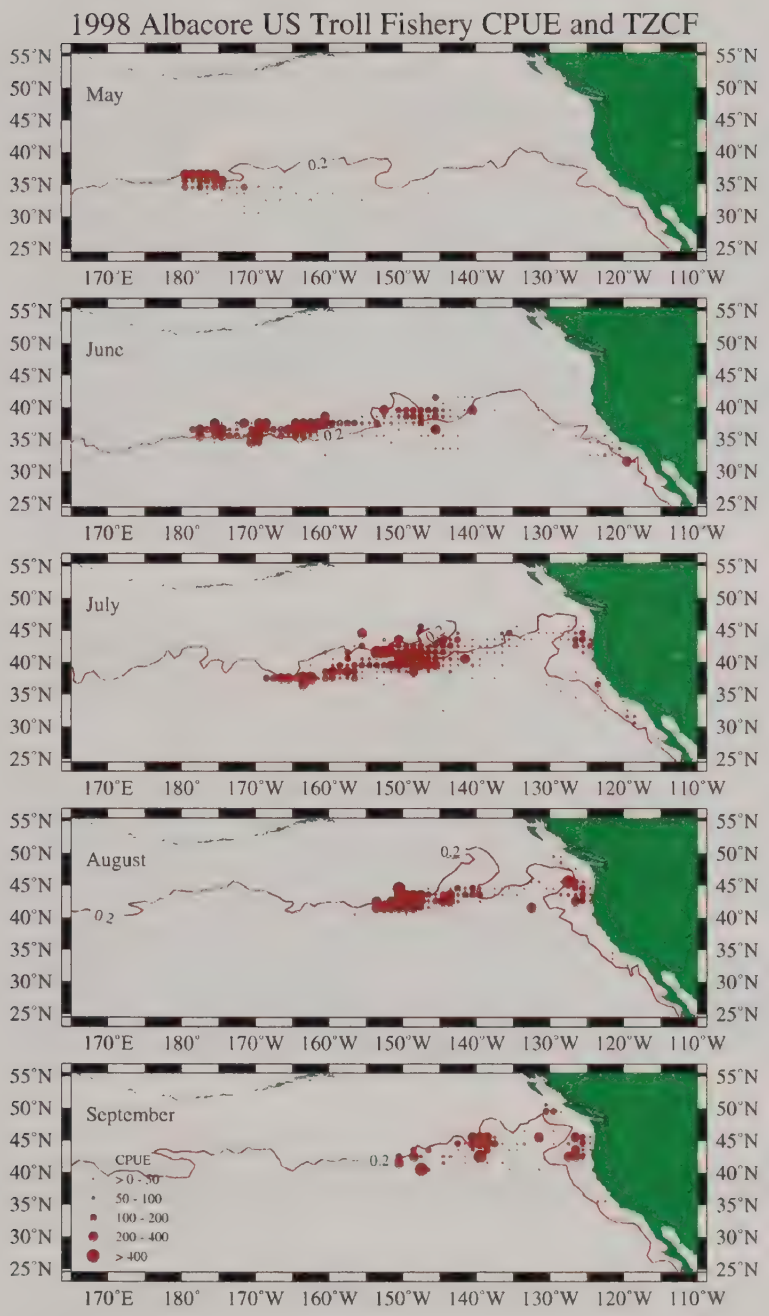

Figure 40. Mean transition zone chlorophyll front and albacore troll CPUE by latitude, averaged between longitude 145°W and 155°W, June-September 1998.

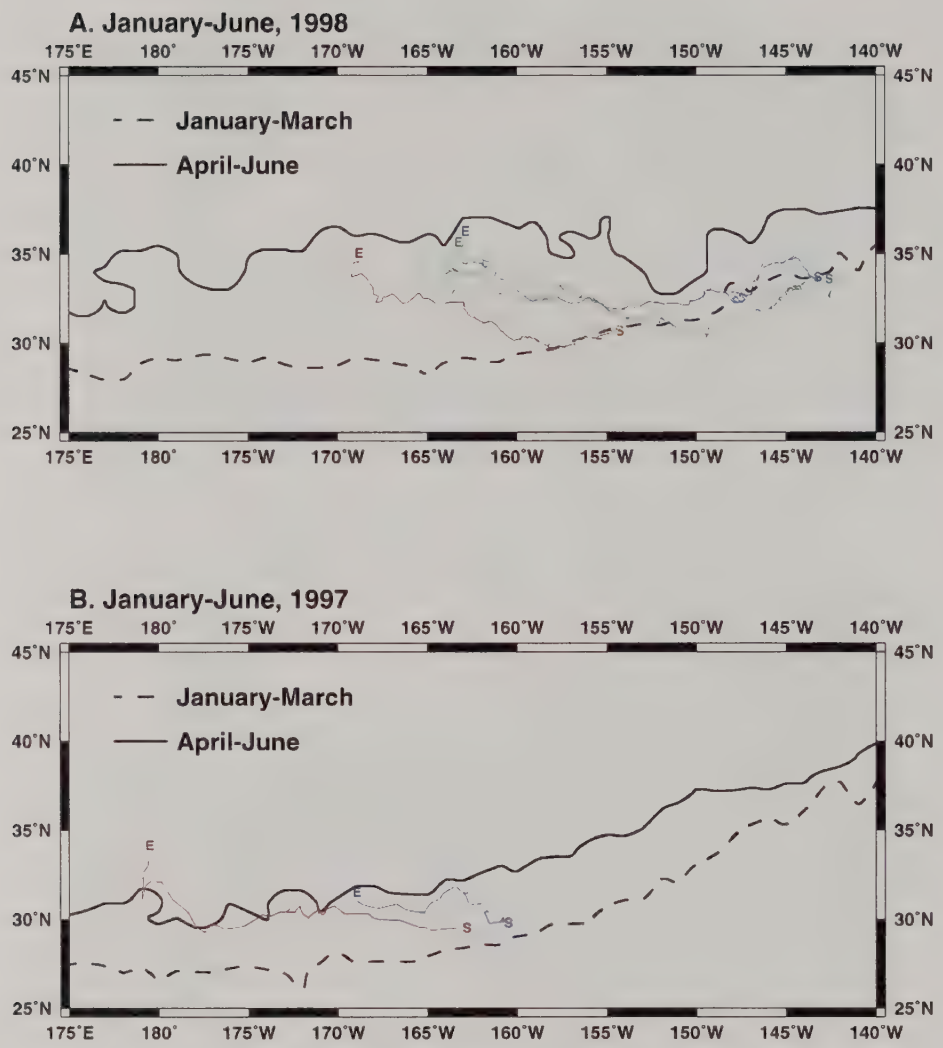

Figure 41. Mean position of the TZCF during the first and second quarters of 1997 and 1998 together with movement paths of loggerhead turtles from satellite telemetry. "S" and "E" denote start and end of the turtle tracks. The dashed and solid lines denote the position of the TZCF during the first and second quarters, respectively.

1.0 mg/m^3 were observed along the northern edge of the TZCF (Fig. 42). These represent high values compared to previous years, and a positive response from high trophic level species was anticipated.

However, in 1999, albacore CPUE was one-fourth of the 1998 level, and in 199, all Laysan albatross chicks monitored at French

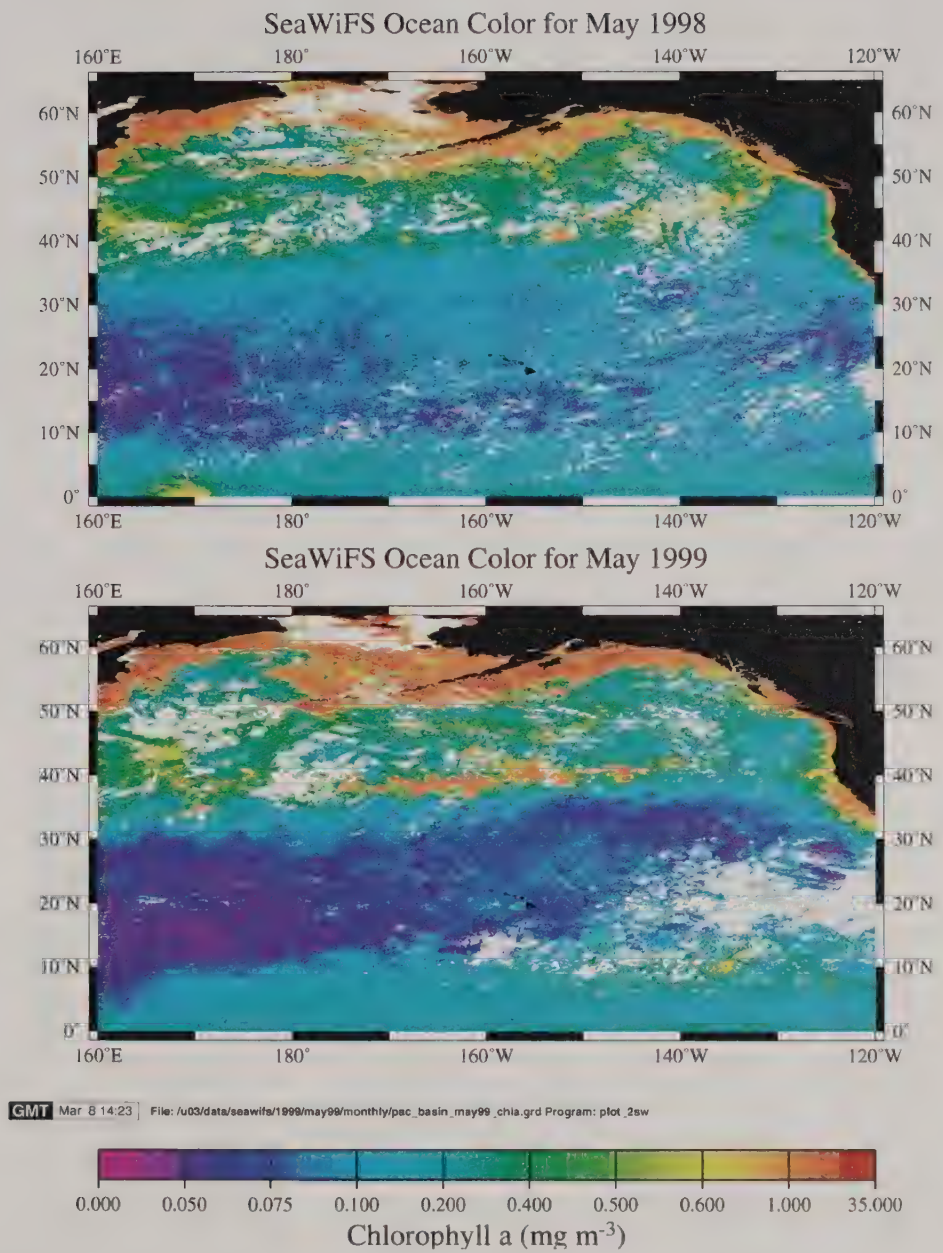

Figure 42. Surface chlorophyll in May 1998 and 1999.

Frigate Shoals died. Albacore fishermen reported weak frontal structure in 1999, and the high mortality of Laysan albatross chicks was attributed to unusually long absences of parents from the nests. It is now hypothesized that the high chlorophyll at the TZCF in 1999 indicated a lack of grazing and hence an unproductive food web for high trophic levels.

A time series of the winter (January and February) position of the TZCF shows considerable variation from 1997 to 2000 (Fig. 43). In winter 1997, high surface chlorophyll was observed as far south as latitude 30°N in the central Pacific but was located north of latitude 40°N in parts of the eastern Pacific (Fig. 39). In winter 1998, there was a southward shift in the TZCF; hence, the presence of the southern latitude of high surface chlorophyll both in the central and eastern Pacific by as much as 750 km in the eastern Pacific (Fig. 40). However, in the winters of 1999 and 2000 the TZCF shifted north from the 1998 position by an average of about 300 km over a range of around 4,000 km longitude, resulting in an approximately 50% drop in surface chlorophyll over a region of 1.2 million km^2 (Fig. 43). Thus, from year to year the remotely sensed chlorophyll data document changes in areas of high and low surface chlorophyll by hundreds of thousands of square kilometers and shifts in the spatial distribution of entire food webs and migration routes hundreds of kilometers north or south.

These interannual changes appear to be indicators of large-scale ocean and atmosphere changes. For example, the southward shift of the TZCF in the winter of 1998 may have been a response to the southward shift of storm tracks observed in the 1997-98 El Niño, which could vertically mix the usually stratified subtropical water. The northward shift in the boundary of high chlorophyll water in the winters of 1999 and 2000 in the central Pacific and the southward shift in the eastern Pacific compared to 1997 could be a response to the 1999-2000 La Niña. The La Niña has a mid-latitude response characterized by sea surface warming in the central Pacific and cooling in the eastern Pacific. A warming in the mid-latitude central Pacific will increase vertical stratification leading to low surface chlorophyll and a northward shift in the high surface chlorophyll boundary. Likewise, a cooling in the eastern Pacific will

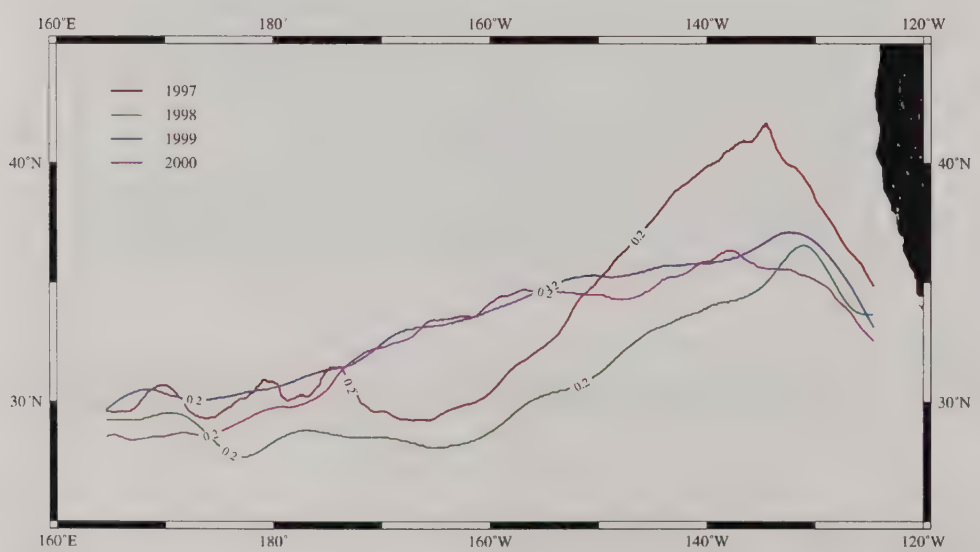

Figure 43. The mean January-February positions of the transition zone chlorophyll front marking the boundary between the high and low surface chlorophyll regions, for years 1997-2000.

decrease vertical stratification leading to high surface chlorophyll and a southward shift in the high-surface chlorophyll boundary. However, it is also known that the mid-latitude North Pacific responds to a decadal oscillation, termed the Pacific Decadal Oscillation (PDO) which also exhibits a mid-latitude dipole pattern in ocean temperature between the central and eastern Pacific. Since 1977 the PDO has exhibited a mid-latitude ocean temperature pattern characterized by a cool central Pacific and a warm eastern Pacific. This pattern will produce the shape of the TZCF seen in 1997, with its dip to the south in the central Pacific and rise to the north in the eastern Pacific. However, the pattern of the TZCF observed in 1999 and 2000 is consistent with a shift in the PDO phase. Warm stratified water in the central Pacific produced a northward expansion of the low chlorophyll water, while cooling and increased mixing in the eastern Pacific produced a southward movement of high chlorophyll water. Is the shape of the TZCF providing an early indication of a phase shift in the PDO? A few more years of data will be needed to determine whether this biological change is a strong mid-latitude La Niña response or the beginning of a new phase of the PDO. The results to date, however, show significant interannual biological variation in the mid-latitude North Pacific and illustrate how satellite ocean color can serve as an excellent tool to monitor this variation.

CENTRAL NORTH PACIFIC ECOSIM

The NMFS has recently called for incorporation of ecosystem considerations in fishery management plans. Managers have been asked to consider the impacts of fisheries on species which compete with, prey upon, or are preyed upon by harvested species. To this end, HL scientists have been collaborating in a National Science Foundation-funded research with scientists from the University of Wisconsin in investigating the role of apex predators in the pelagic ecosystem. The Central North Pacific Ecosystem Project Team also includes scientists from the University of Washington and the University of British Columbia. The project team constructed an Ecopath/Ecosim http://www.fisheries.com/) model of food web (Fig. 44) and fishery interactions (Fig. 45) for the central North Pacific using known trophic relationships, estimates of mortality rates, harvests of commercially important species, and estimates of exploitation rates and biomass for target tuna species in the 1990s. Most other harvested species (e.g., sharks and billfishes) were assumed to be almost fully exploited. The model included commercially important species, as well as bycatch and forage species for which vital rates were hypothesized. The team used the model to simulate a gradual reduction in exploitation rates, following a reversed trajectory of the industrial-scale expansion of longline, pole-and-line, troll, purse-seine, and high-seas driftnet fisheries since the late 1940s (Fig. 46).

The Ecosim model predicted a much greater abundance of sharks, marlins, broad-

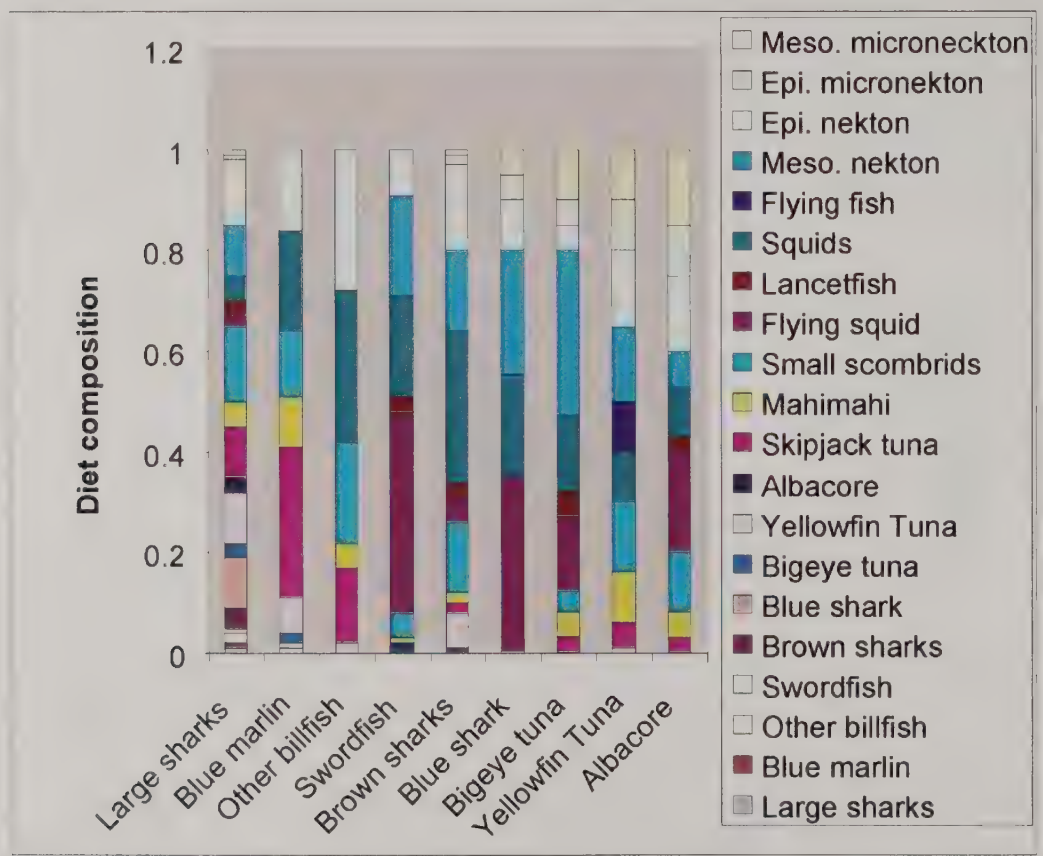

Figure 44 Diet composition of major species and types of predatory pelagic fishes in the central North Pacific.

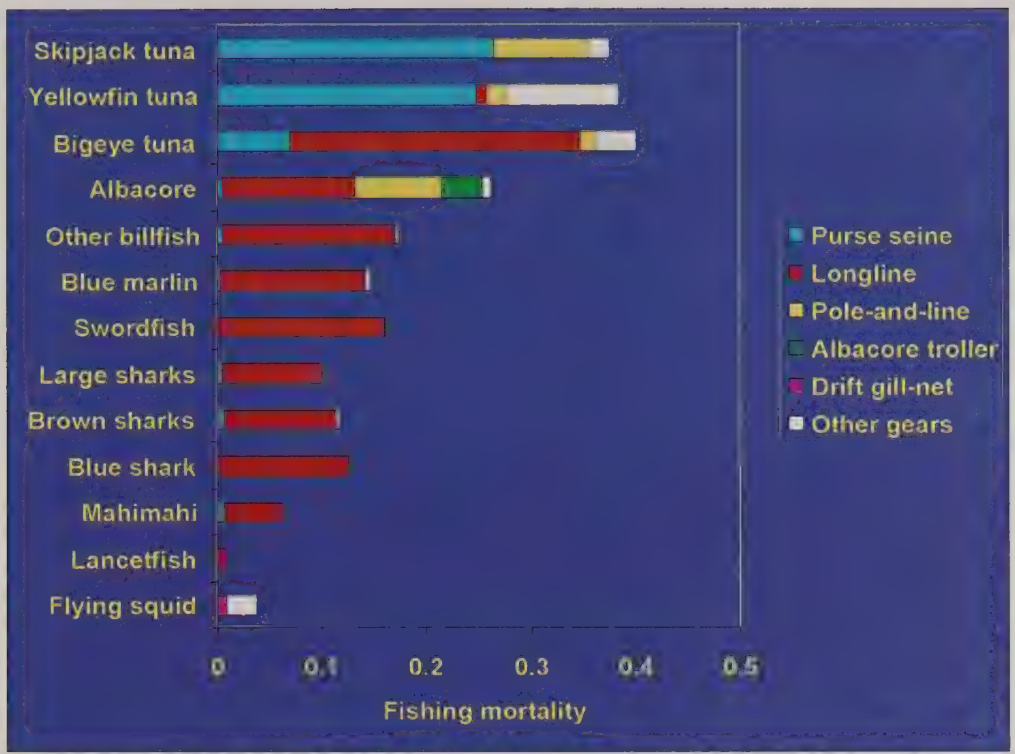

Figure 45. Contribution of various fishing methods to fishing mortality of major species and types of pelagic predators.

bill swordfish, and large tunas prior to the industrial-scale fishery (Fig. 47). In contrast, mahimahi and several smaller species were less abundant than recently observed. Biomass changes attributable to fishing mortality were displayed separately from those caused by changes in prey abundance or predation (Fig. 48).This analysis suggested that indirect effects of fishing (i.e., trophic effects) contributed both to the current low abundance of slower growing groups such as sharks and marlins and to the increased abundance of faster growing species. As exploitation increased across the Pacific, species like mahimahi may have become more abundant as their less-productive competitors and predators (tunas, billfishes, and sharks) became less abundant. The current food web configuration is a product of both the direct effects of fisheries-induced mortality and the indirect effects of species interactions that are altered by exploitation.

The exploitation of pelagic sharks by longline fisheries has recently raised questions about changes in the food webs that include sharks as apex predators. The project team developed two methods for addressing this issue. First, they developed a bioenergetics modeling approach that estimates the amount of prey resources required to support a shark through its life history. That model was expanded to a stable age distribution for the blue shark population of the central North Pacific and used to evaluate the ecological results of different exploitation effects. Second, at an ecosystem scale, the team applied a version of the Ecopath/Ecosim models to evaluate changes in community structure caused by shark exploitation.

The bioenergetic model provided a comparison between the forage demand required by a cohort of sharks with that for other

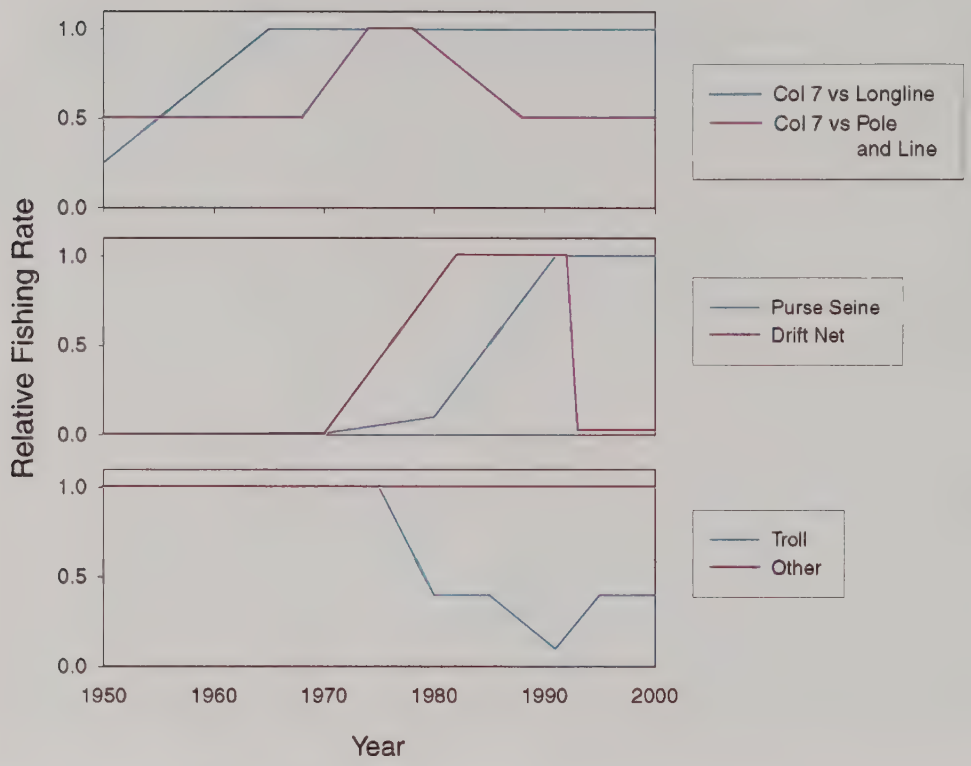

Figure 46. Relative fishing rates of various fishing methods projected through the year 2000.

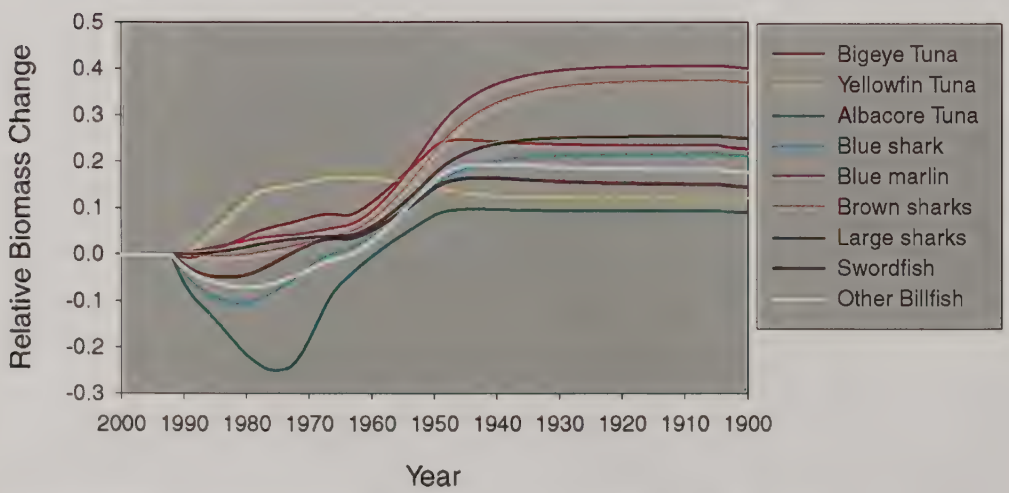

Figure 47. Relative biomasses of major pelagic fishes hindcast back to the year 1900 from the present.

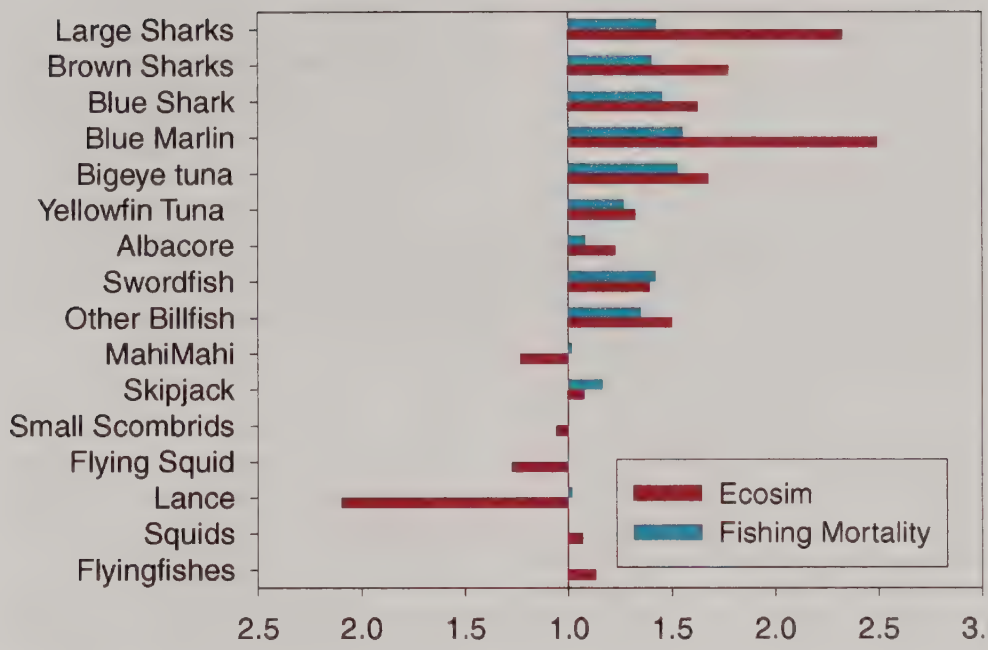

Figure 48. Relative biomass changes attributable to direct fishery harvest versus indirect alteration of predator and prey abundances by fishing.

predators (e.g., tunas). The results show that the per-capita lifetime consumption of prey by sharks is much higher than for other predators. Even though sharks eat less per unit of time than tunas, they live much longer. Moreover, the model showed that shark populations declined more severely than other predators under increased exploitation. Thus the bioenergetic model suggested that exploitation of sharks could have greater trophic effects than the exploitation of tuna. However, if reduced predation by sharks is replaced by increased predation by their competitors on the same prey, there would be little net impact. This was the outcome of the ecosystem model, which suggested that declines in shark populations had little impact on the food web. This unexpected result contradicted a popular idea that pelagic sharks must be "keystone predators" which have a stabilizing influence on food web diversity and biomass. The simulation was repeated with the diet of sharks exaggerated toward greater selectivity for other large predators at the top of the food chain. With the diets altered in this manner the simulations did produce modest effects on tunas, and billfishes but still had very little effect on the majority of food web components. These results are interesting in relation to concern over shark harvests. Pelagic sharks may be more vulnerable to overexploitation than pelagic teleosts but may play only a minor role in structuring pelagic food webs.

HIGHLY MIGRATORY SPECIES OCEANOGRAPHY

The HL oceanographic research in support of highly migratory (HMS) species principally focuses research efforts on the North Pacific swordfish (*Xiphias gladius*) and bigeye tuna (*Thunnus obesus*) resources and the Hawaii-based longline fishery that targets them. Stock assessment of these pelagic species is generally based on longline fishery CPUE as an index of abundance of the stock. Unfortunately, fishery-dependent CPUE does not necessarily reflect abundance of the stock but rather the catchability of the stock. Catchability, in turn, is dependent to a considerable extent upon variable environmental conditions. The primary objectives of HMS oceanography research is thus to characterize the species-specific essential and preferred habitat, to examine the influence of environmental variability on CPUE, and to gain insight that will ultimately help interpret fishery performance.

Because of the highly dynamic nature of the ocean on varying temporal and spatial scales, a multiplatform approach of satellite remote sensing, in situ shipboard surveys, and moored instrument arrays is undertaken in the oceanographic assessment. Satellite-mounted sensors provide near real-time synoptic data coverage on the large scale. Satellite data used include sea surface temperature from NOAA advanced very high resolution and governmental operational environmental satellite (GOES) radiometers, ocean color from the Sea-viewing Wide Field-of-view Sensor (SeaWiFS), sea surface height from the altimeter aboard TOPEX/POSEIDON, and ocean winds from the advanced microwave instrument scatterometer aboard ERS-2. In situ surveys, which principally involve along-track acoustic Doppler current profiler and a series of conductivity-temperature-depth casts and discrete-depth water sampling stationed along predetermined transects, describe processes that occur on the local and mesoscale and provide the information necessary for ground-truthing and subsurface interpretation of the satellite tools. Moored arrays furnish the information needed to assess water column structure over time. These data are considered together with concurrent distribution, abundance, and CPUE patterns of swordfish and bigeye tuna to conduct assessments.

The HMS oceanography program at HL benefits from strong past and ongoing collaborations with academia, including scientists from oceanography departments at the University of Hawaii at Manoa, the University of Washington, and the University of South Florida.

Swordfish

Over the last 4 years, developing an understanding of the relationship between the Hawaii-based swordfish fishery and the oceanographic environment has been and continues to be a research focus for HL scientists. During the peak winter-spring fishing season, the Hawaii-based swordfish fleet commonly operates in a region nominally referred to as the Subtropic Frontal Zone (SFZ) (Fig. 49). Multiple, planetary-scale, individual semipermanent fronts accentuate the frontal zone--the two most prominent, the south subtropical front (SSTF) and the subtropical front (STF), climatologically located at latitudes 32°-34°N and at 28°-30°N. Distinct physical oceanographic parameters and unique biological responses have been found to characterize each frontal system.

The SSTF is climatologically positioned between latitudes 28°N and 30°N during the months of January to April after which the front rapidly migrates northward with increasing insolation. The 20°C and 35.0 surface isotherm and isohaline, respectively, are usually seen embedded in the frontal gradients and are readily detectible by in situ and satellite sensors. Vertically, the thermocline shoals to a depth of about 70-80 m. Nutrients are transported into the euphotic zone, and production and standing stock of phytoplankton sharply increase at the subsurface chlorophyll maximum. The shoaling of the thermocline is also believed to physically concentrate swordfish and their prey closer to the

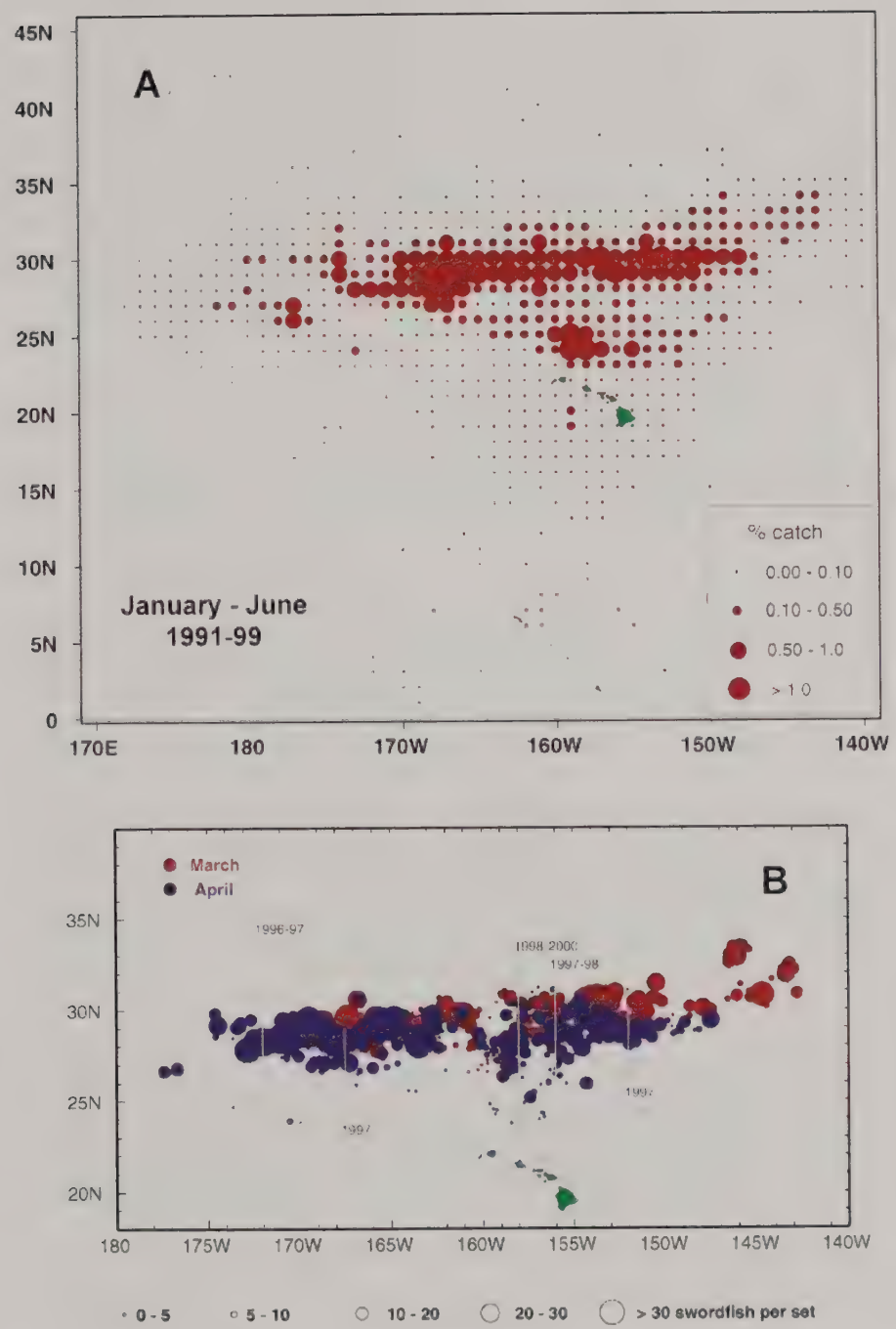

Figure 49. (a) Swordfish harvest (%) for the Hawaii-based longline fishery by 1° latitude x 1° longitude statistical areas and (b) NOAA ship *TC* survey tracks (1996-2000) and swordfish (*Xiphias gladius*) monthly catches per confidential set during March-April 1996-99.

surface longline gear. To the north, the STF (17°C surface isotherm, 34.8 isohaline) is typically positioned between latitudes 31°N and 33°N during January to April and also rapidly migrates northward moving into the summer months. A surface chlorophyll front (the transition zone chlorophyll front or TZCF) exhibiting a twofold increase in concentration is also normally associated with this front and is readily monitored by the SeaWiFS ocean color satellite. Dynamically, the increase in chlorophyll can be ascribed to the weakened vertical density structure and facilitated flux of nutrients into the surface waters.

From annual shipboard surveys, large interannual variability in geoposition and frontal intensity of the SSTF and STF are observed. In the time series of five cruises, the SSTF occupied positions ranging over five degrees of latitude (555 km or 300 nmi) (Fig. 50). Although sections are being compared, these shifts appear to be basin-scale phenomena. Conceivably, the very strong 1998 El Niño and subsequent 1999 La Niña may likely have had a large role in observed patterns.

Bigeye Tuna

During 1999, a new research initiative (with funding from JIMAR's Pelagic Fisheries Research Program (PFRP)) was launched to study the role of the environment on bigeye tuna aggregation and vulnerability to fishing. As with swordfish, the research is based on the combined oceanographic information acquired from satellite, moored and shipboard platforms, and concurrently collected commercial and research fishery data. In December 1999, the BIGEYE mooring was deployed about 185 km southwest of the island of Niihau at latitude 20°36.0'N, longitude 161°24.2'W in 4,670 m water by the NOAA ship *Ka'imimoana* (Fig. 51). The mooring is instrumented to record temperature at 13 depths, current velocity at 5 depths, salinity at 2 depths, and dissolved oxygen at 1 depth in the upper 700 m. The position of the mooring was selected based on historical bigeye tuna CPUE, variability of CPUE, proximity to TOPEX altimetric satellite crossover paths, and variability of oceanographic structure.

Three shipboard surveys (April 1999, November 1999, and April 2000) aboard the NOAA ship *Townsend Cromwell* have been conducted 1) to survey the spatial representation of the mooring location and 2) to examine the influence of mesoscale dynamic variability on the physics and biology through the water column. Particularly noteworthy was the shipboard bisection of two cyclonic eddies during the November cruise with the help of near real-time GOES sea surface temperature (SST) information relayed to the ship from the Hawaii CoastWatch site located at HL. Surface thermal gradients measured both by satellite and in situ methods were stronger at the more recently formed (ca. 1 month) eddy, Mikalele, but subsurface vertical structure was considerably more developed at the older (ca. 6 months) eddy, Loretta. Strongest ADCP current velocities measured in the eddy fields exceeded 70 cm/sec (1.3 knots) and 80 cm/sec (1.5 knots) at Mikalele and Loretta, respectively. As expected, the surveys revealed marked vertical differences in the physical and biological structure of the eddies. Substantial increases in macronutrients, chlorophyll-*a*, large eukaryotic phytoplankton, and primary, as well as new production, were measured in both eddy cores as compared to control station locations outside of eddy influence. The responses at the older eddy Loretta, however, were substantially magnified (Fig. 52). Research efforts toward bigeye tuna oceanography will continue to be emphasized during the upcoming year.

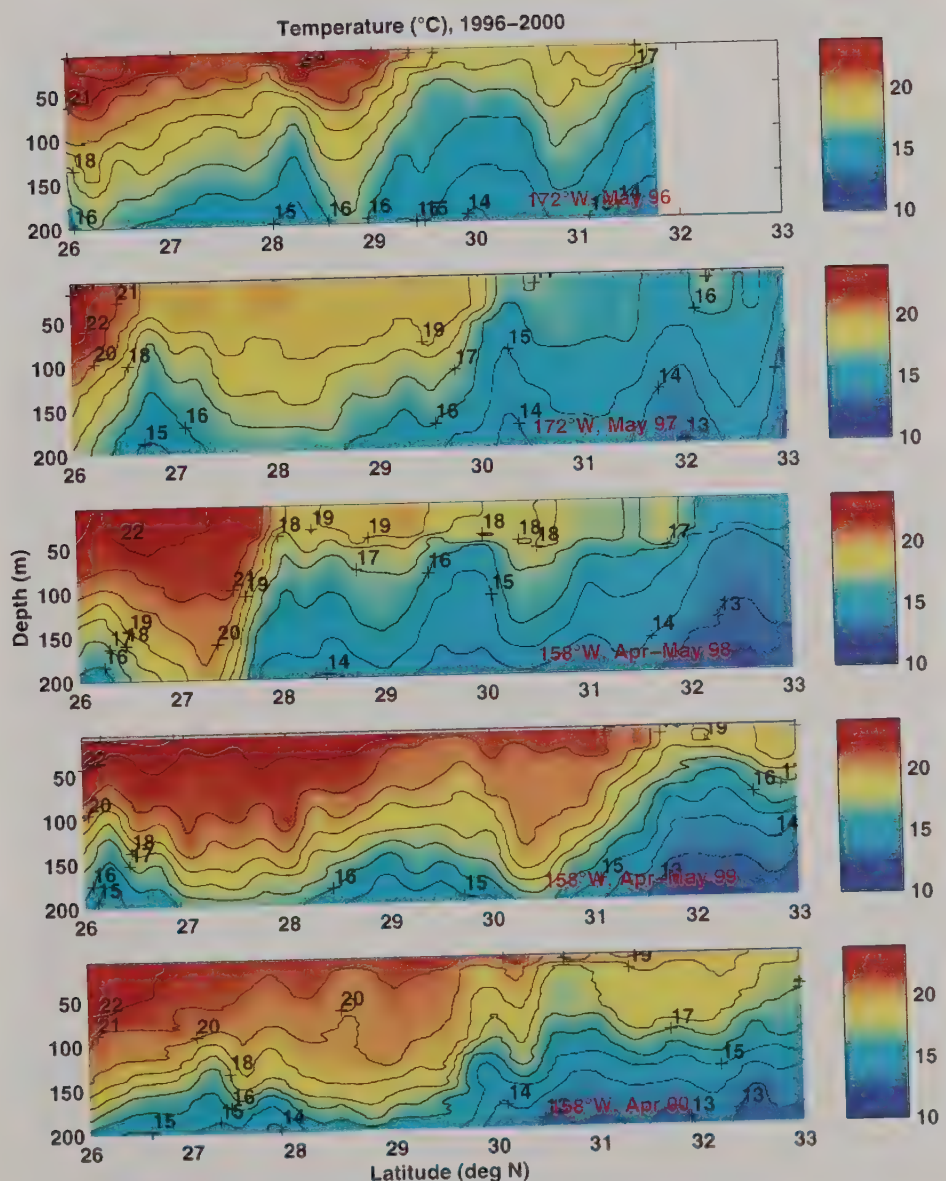

Figure 50. Comparative vertical sections of temperature (°C) from annual surveys 1996-2000; 1996-97 surveys conducted along longitude 172°W; 1998-2000 along longitude 158°W.

Figure 51. Schematic representation of the BIGEYE mooring located at latitude 20°36.0'N, longitude 161°24.2'W.

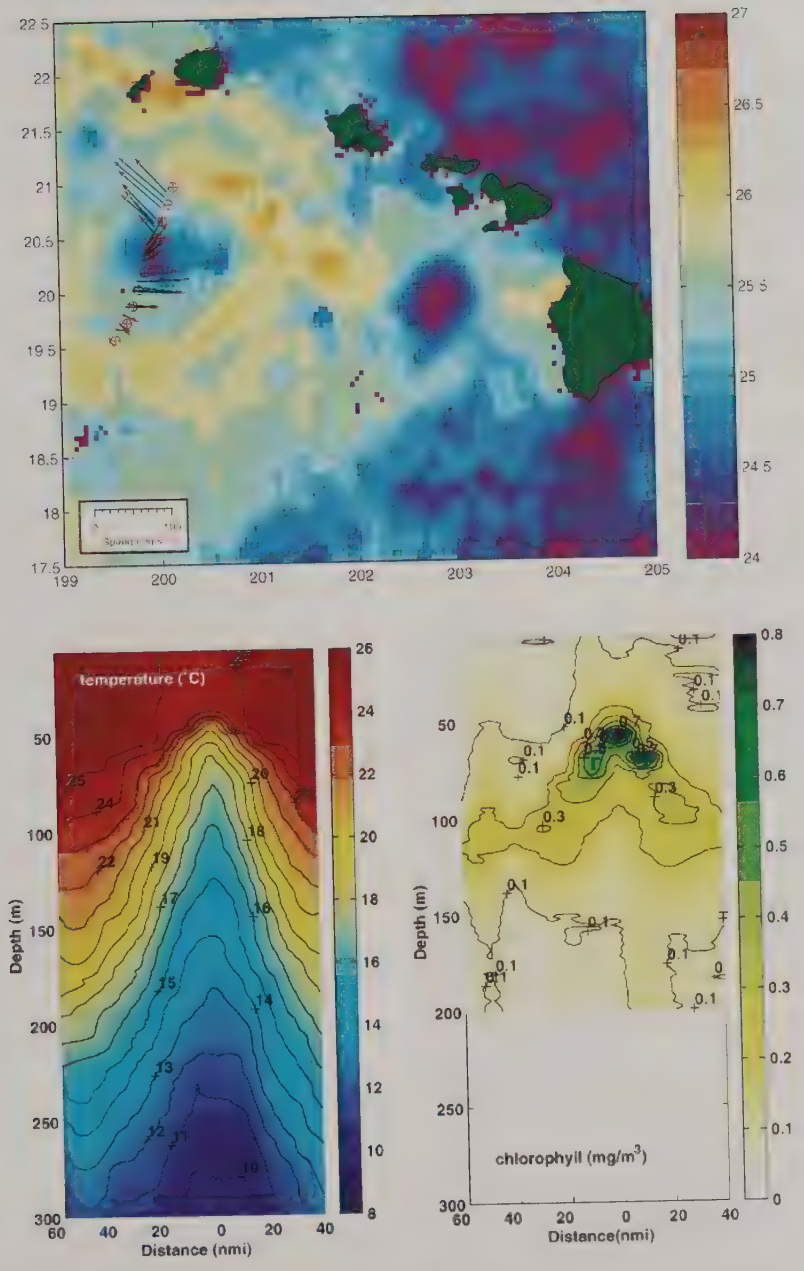

Figure 52. NOAA ship *TC* November 1999 survey of the cyclonic eddy, Loretta: (a) GOES-10 false color sea surface temperature image, shipboard ADCP current velocity vectors (arrows), and hydrographic station positions (circles); vertical section of (b) temperature (°C) and (c) chlorophyll (mg/m^3) through the eddy field. Data are presented as distance (nmi) relative to eddy center.

INSULAR ECOSYSTEM MONITORING

Background Information

In support of the NMFS missions to recover protected species, maintain healthy living marine resource habitats, and build sustainable fisheries, the HL has instituted an opportunistic long-term insular ecosystem monitoring program of the Northwestern Hawaiian Islands (NWHI). This program has been initiated to support ongoing efforts to:

- Recover critically endangered Hawaiian monk seals and threatened Pacific sea turtles.
- Better understand and manage bottomfish and crustacean resources.
- Better protect biodiversity and essential fish habitat associated with coral reef ecosystems.

The health and condition of all living marine resources are dependent upon the nutrients, temperature, salinity, dissolved oxygen, ocean currents, wave energy, and other ocean conditions characterizing their essential habitat. Changes in ocean conditions often result in biological changes throughout the ecosystem and could have significant impacts on survivability of endangered species or economic viability of limited fishery resources. Significant changes in ocean conditions, both biotic and abiotic, are known to occur over a large range of temporal scales. Many insular and pelagic species demonstrate diurnal behavior patterns such as large vertical or horizontal migrations associated with foraging and survival. Diurnal variations of physical processes of the insular habitat, such as tidal currents, sea level height, and ocean mixing, play an important role in modulating the biological processes of the coastal zone. Seasonal variations of atmospheric and oceanographic conditions are frequently associated with significant behavior responses, such as seasonal breeding and spawning or horizontal migrations. In recent years, interannual (year-to-year) variations in weather and biological conditions associated with the El Niño/Southern Oscillation have received significant media attention around the globe. Decadal shifts in ocean and atmosphere conditions are known to have dramatic effects on marine ecosystems. The entire NWHI ecosystem is believed to have undergone a significant decadal shift in 1977 that affected biological production over many trophic levels.

Goals and Objectives

The primary goal of HL's insular ecosystem monitoring program is to examine seasonal, interannual, and decadal variability of ocean conditions in the NWHI to enable investigators to better examine relationships between the health of the various managed populations (monk seals, turtles, lobsters, bottomfish, and reef fish) and the environment over these various time scales. A time series approach is crucial to improving our understanding of population fluctuations, particularly with regard to natural versus anthropogenic changes. The specific objectives of the insular ecosystem monitoring program are to utilize a multiplatform approach consisting of:

- Shipboard observations of the ocean's high resolution vertical structure at select sites.
- Satellite remote sensing of ocean surface conditions with good spatial resolution over time.
- Moored oceanographic buoy observations providing high resolution time series of the ocean's vertical structure at specific sites.

Major Research Activities

Shipboard Observations

Conductivity-Temperature-Depths–The central component of the shipboard portion of the oceanographic monitoring program is a series of 10 CTD (conductivity, temperature, and depth) stations along the NWHI (Fig. 53). These monitoring stations were established in May 1999 to begin a long-term time series of the vertical structure of temperature, salinity,

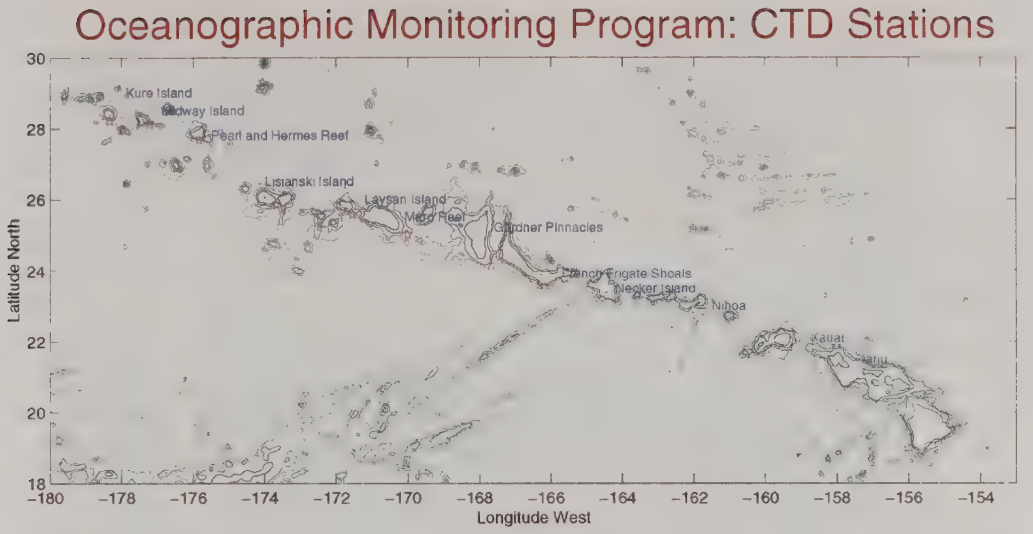

Figure 53. Locations of permanent conductivity-temperature-depth (CTD) stations along the Northwestern Hawaiian Islands established in May 1999 to monitor long-term changes and trends in oceanographic conditions.

fluorometry (chlorophyll), and dissolved oxygen in the upper 500 m of the water column. The 10 stations, ranging between Nihoa Island in the southeast to Kure Atoll (KUR) in the northwest, were selected based on their proximity to the major breeding islands for Hawaiian monk seals or important fishing grounds. Since these observations are opportunistic (piggy-back on other research cruises), efforts were made to minimize disruption to normal cruise activities by locating the stations along or near standard tracklines of the NOAA ship *Townsend Cromwell* (*TC*).

In addition to the CTD-mounted fluorometer, which provides total chloro-pigments, concurrent discrete depth (surface, 80 m, 100 m, 125 m, and 150 m) water sampling is conducted for extractive fluorometric analysis to determine chlorophyll-*a* and for quality assurance and calibration of the in situ sensor. The discrete depths were selected to bracket the average depths of the SCM. Chlorophyll observations provide information for monitoring the phytoplankton standing stock as well as capturing biological responses to physical changes in the water column. Surface water samples are used to calibrate or ground-truth satellite ocean color sensors.

During the first year of this program, May 1999 through May 2000, some or all of the CTD stations along the NWHI were occupied during seven cruises. Significant temporal and spatial variability of the vertical structure of both temperature and chlorophyll (Fig. 54) are observed along the NWHI. Although it is premature in the current time series record to define the annual cycle, strong seasonal variability is suggested by pronounced differences of both temperature and chlorophyll between October 1999, which is representative of late summer conditions, and May 2000, which is representative of late winter conditions. During October, temperature and chlorophyll isopleths were observed to be relatively shallow to the northwest and relatively deep to the southeast. This general northwest to southeast sloping of the isopleths, particularly the sharper gradients to the northwest, are indicative of the south subtropical front (SSTF) (see section 4 on Fisheries Oceanography). Strong doming or shoaling of temperature and chlorophyll isopleths were observed at the Pearl and Hermes Reef (PHR) station near the northwest end of the transect, with isotherms being elevated about 80 m and chlorophyll isopleths being elevated about 30 m, respectively. If this doming is real and not due to lack of synopticity of the PHR and Midway (MID) observations, it would suggest strong mesoscale eddy activity with upwelling-driven

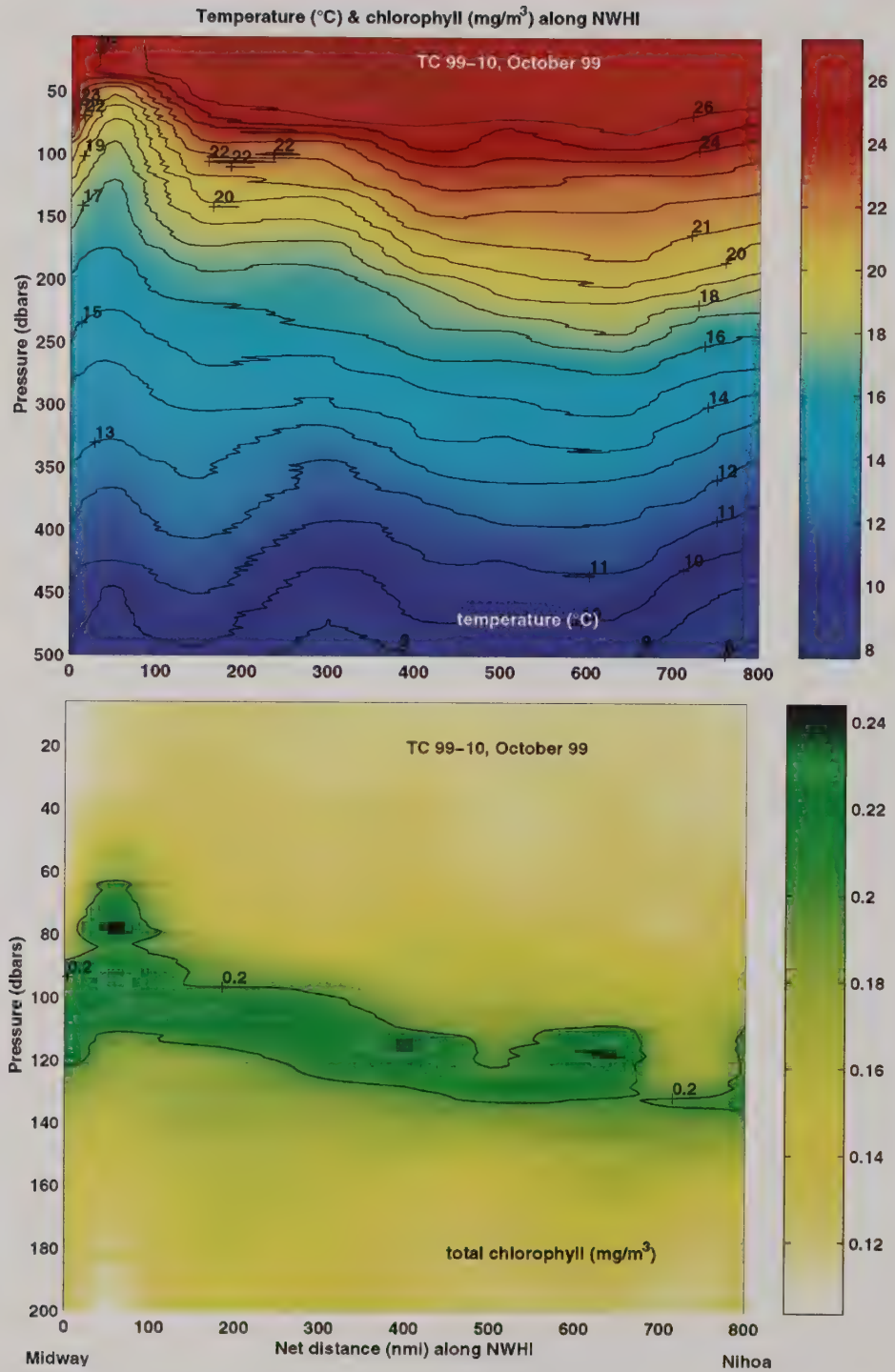

Figure 54. Transect of vertical structure of temperature to 500m and total chlorophyll to 200m at long-term CTD stations along the Northwestern Hawaiian Islands from Nihoa Island to Midway Atoll during October 1999.

nutrient enrichment in the center. If due to the 8-day interval between observations, it suggests a relatively rapid shift in the position of the subtropical front (STF). During May, the vertical structure of both temperature and chlorophyll was much more complex. Vertical isotherm differences in the pycnocline were as large as 100 m between adjacent stations, suggesting either very strong internal wave activity or intrusions or water masses between the various passes in the Hawaiian Ridge. This complex vertical structure was superimposed over a weaker northwest to southeast slope of the isopleths similar to that observed during October.

The general trend of shallower chlorophyll isopleths to the northwest suggests enhanced productivity at this end of the archipelago. If this observation is found to persist, it would tend to support observations of stable or increasing populations of Hawaiian monk seals at PHR, MID, and KUR in recent years. Likewise, if the relatively deep chlorophyll maximum found at the southeastern stations persists, it may tend to partially explain the observed decline in the population of the monk seals at French Frigate Shoals (FFS). As this time series lengthens over the coming years, these questions will become easier to address.

Acoustic Doppler Current Profiler (ADCP)–Another key component of the insular ecosystem monitoring program involves shipboard observations of ocean currents using an ADCP. The ADCP, which measures frequency shifts in sounds transmitted from four orthogonal transducers mounted on the hull of the *Townsend Cromwell*, records profiles of velocity at 8 m vertical intervals to depths of about 250-300 m. Real-time graphical displays of the velocity profiles every 5 minutes provide scientists and ship's officers a valuable tool to assist them in understanding oceanographic processes affecting the ecosystem or fishing operations.

The vertical and horizontal structure of the currents are used to better understand the interaction between biological and physical processes of the NWHI ecosystem. The ocean currents provide mechanisms for nutrient enrichment and productivity enhancement, larval and sediment transport, and advection of ecosystem threats like marine debris and alien species (see section on Corals Reefs and Marine Debris). HL oceanographers are utilizing a 12-year time series of ADCP observations along the Hawaiian Ridge to examine the spatial and temporal variability of flow in the NWHI ecosystem. To date, processing has been completed for almost 10 years of the 12-year time series of ADCP observations. Once the processing is completed, the full-time series will be used to examine mean flow conditions as well as seasonal and annual cycles. Once patterns in the flow field are characterized, the time series will be related to biological time series in the NWHI to better understand the role the ocean currents play in regulating managed populations, such as Hawaiian monk seals and lobster and bottomfish stocks.

To better understand the ecosystem dynamics at two of the primary lobster fishing banks in the NWHI, Necker Island and Maro Reef, the annual lobster stock assessment and tagging cruises for the past 3 years have conducted nighttime ADCP transects radially outward from the banks (Fig. 55). In addition to describing the spatial structure of the ocean currents around and supporting these banks, CTDs, expendable bathythermographs (XBTs), and plankton tows using a 1-m diameter ring net have been conducted. These surveys are being used to examine the spatial variability (horizontal and vertical) or patchiness of the zooplankton around these banks and therefore better understand the essential fish habitat of lobsters and other components of these bank ecosystems.

In addition to using ADCP observations to better understand physical and biological interactions and how they relate to the dynamics of the NWHI insular ecosystem, HL oceanographers are utilizing the ADCP time series along the Hawaiian Ridge to assist collaborating investigators from five academic institutions on the Hawaii Ocean Mixing Experiment (HOME). The HOME is an integrated program funded by the National Science Foundation (NSF) to study the role of tidally induced topographic mixing in maintaining the large scale thermohaline circulation of the world's oceans. Observed mixing rates in the abyssal ocean are an order of magnitude less than that required to maintain the large-scale circulation. Recent observations suggest that much of the mixing of the

ocean interior occurs near significant topographic features, like the Hawaiian Ridge. The challenge of this program is to identify the mechanisms which are active enough over a sufficient space-time domain as to have a global impact.

Using the processed ADCP velocity data, the vertical shear of velocity has been computed for about 8 years of the time series. Statistical analysis of the shear profiles along the Hawaiian Ridge have revealed several noteworthy observations. First, the shear observations showed significant spatial (vertical and horizontal) and temporal variability along the Hawaiian Ridge. Second, mean shear profiles computed from 74 transects along the NWHI (Fig. 56) showed three regions of enhanced velocity shear well below the mixed layer at depths between 200 and 300 m. These regions of enhanced deep shear are 1) the vicinity of Kaena Ridge in the Kauai Channel between Oahu and Kauai, 2) the vicinity of Nihoa Island and West Bank, and 3) the area between Gardner Pinnacles and FFS. Interestingly, an independent numerical modeling study from other HOME investigators found high energy flux radiating away from the Ridge at these same three regions and presented similar results at a HOME principal investigators' meeting earlier in the year. Third, shear increased near topography, supporting the hypotheses that shear-forced mixing may be enhanced by interaction with large scale topographic features (Fig. 57). Finally, preliminary attempts to

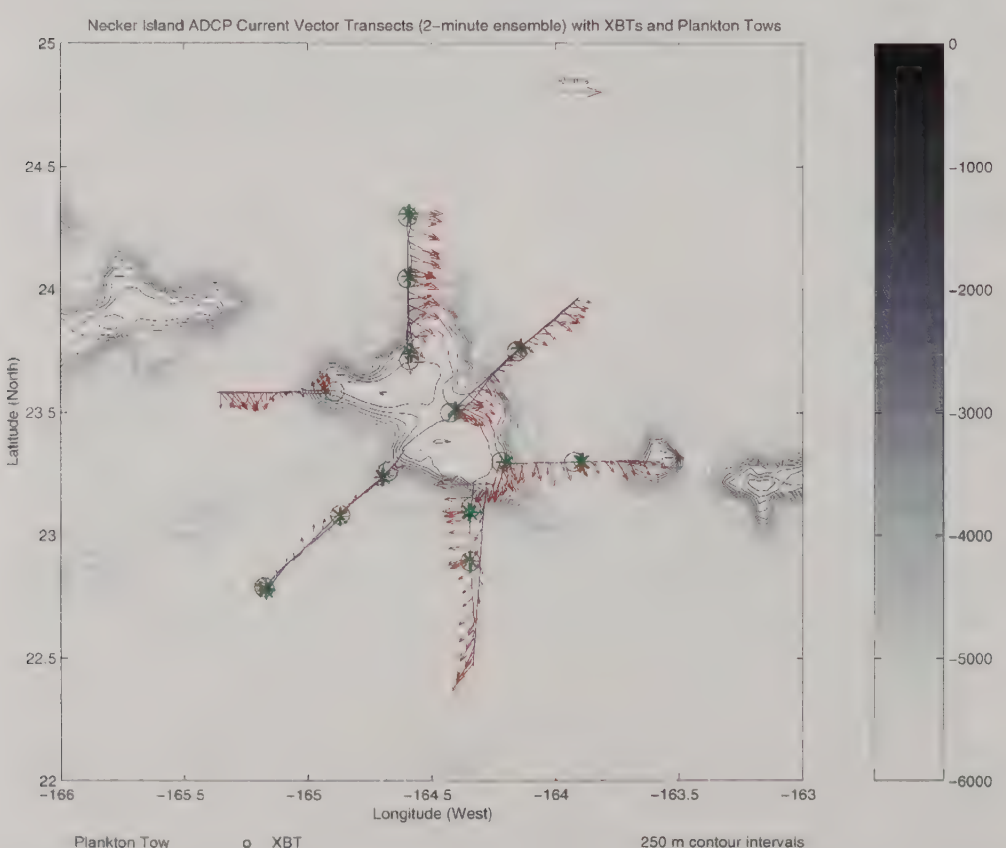

Figure 55. Acoustic Doppler current profiler (ADCP), expendable bathythermographs (XBT) and zooplankton trawl transects from the NOAA ship *Townsend Cromwell* aroound Necker Island in July 1998. Current velocity vectors are shown as red arrows. Locations of XBTs (blank circles) and plankton trawls (green asterisks) are indicated.

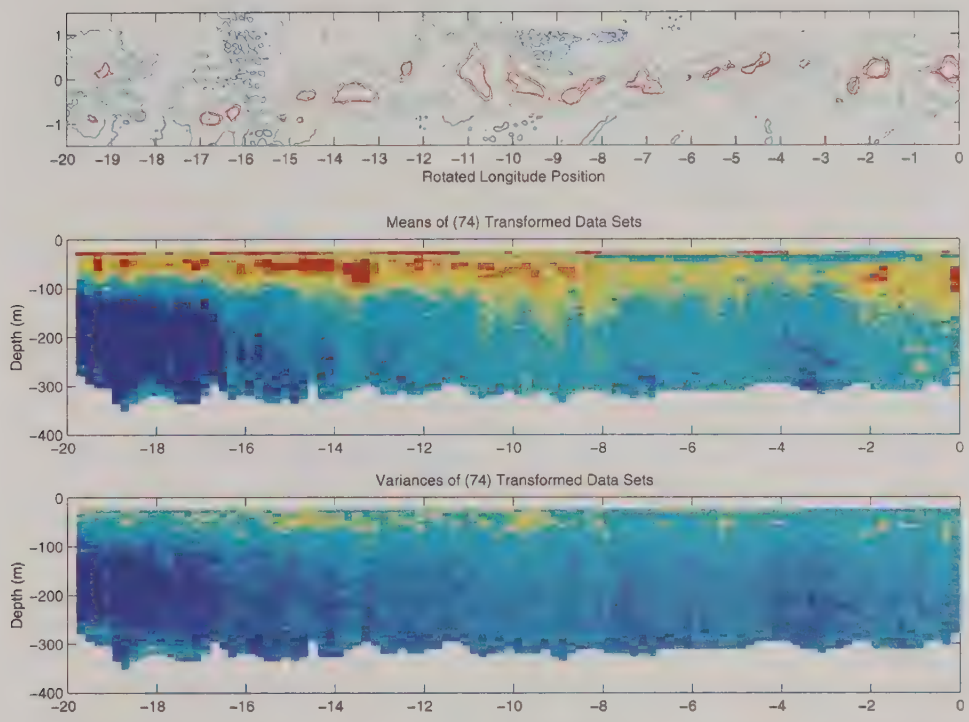

Figure 56. Statistics of vertical velocity shear computed from 74 acoustic Doppler current profiler (ADCP) transects along the Northwestern Hawaiian Islands (NWHI) during the period 1992-98: a) shows map of NWHI along a rotated longitude axis and ±1° of latitude, b) mean vertical velocity shear (s^{-1}) and c)variance of vertical velocity shear.

relate these opportunistic shear observations to tidal cycles have not found any statistically significant relationships. Since these data are not tidally resolving, this finding is not surprising.

Expendable bathythermographs–In collaboration with HOME investigators from Scripps Institution of Oceanography, HL investigators have supplemented CTD profiles during the past year with closely spaced temperature profiles along the Hawaiian Ridge using expendable bathythermographs (XBT) funded by the NSF. HL is very appreciative of efforts by the crew of the TC for taking charge of the deployment and data collection of XBTs during all cruises to the NWHI. The XBTs, which record vertical profiles of temperature from the surface to a depth of 760 m, are deployed every 20 nmi along the Hawaiian Ridge between the Island of Hawaii and FFS and every 50 nmi between FFS and KUR. These temperature profiles provide HOME investigators an opportunity to identify signatures of active or recent ocean mixing. The ongoing analyses of these data are aimed at identifying particular regions or topographic features which tend to show either strong or persistent mixing signatures. Once identified, HOME investigators will target these regions during the multiship intensive survey component of the HOME project.

Since ADCP observations have suggested that shear-induced mixing may be enhanced in the immediate vicinity of large bathymetric features (see above), additional XBTs and CTDs are presently being conducted in conjunction with ADCP transects being run radially outward from Necker Bank and Maro Reef during the nighttime hours of the annual lobster stock assessment cruise.

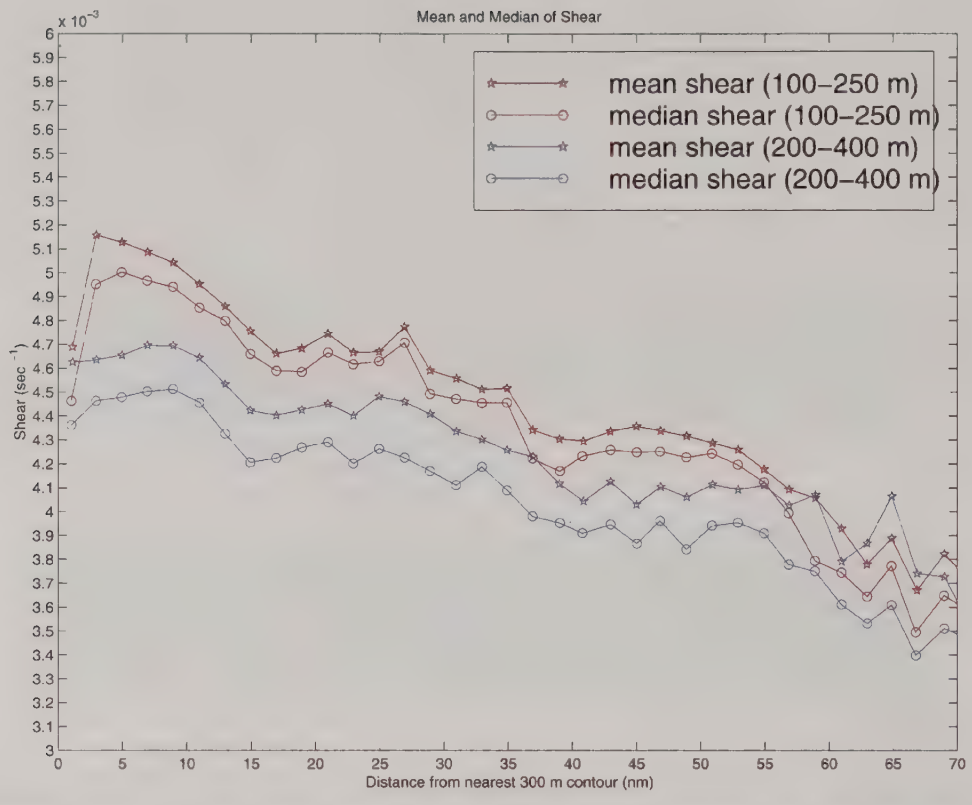
Mean and Median of Shear
x 10^-3
mean shear (100–250 m)
median shear (100–250 m)
mean shear (200–400 m)
median shear (200–400 m)
Shear (sec^-1)
Distance from nearest 300 m contour (nm)

Figure 57. Median and mean vertical velocity shear versus distance from topography (the 300 m isobath along the Northwestern Hawaiian Islands.

The additional XBTs are being deployed in the immediate vicinity of the steep bathymetric slopes to provide HOME investigators additional opportunities to examine relationships between mixing and distance from topographic features.

In addition to the HOME objectives, the increased spatial resolution of the thermal structure along the NWHI provided by the addition of XBT temperature profiles provides HL scientists an improved data set by which to understand the complex dynamics of the NWHI ecosystem. These additional observations will be further enhanced during the HOME intensive survey period scheduled during the fall of 2000. Laboratory scientists are looking forward to working with Scripps scientists to examine very high resolution upper ocean vertical structure measurements using a profiling Sea-Soar instrument.

Thermosalinograph–Sea surface temperatures and salinities are measured along the ship's track using the shipboard thermosalinograph (TSG). An intake pipe in the bow observation chamber allows seawater to continually pass over the TSG sensors to allow continual time record of the surface conditions of temperature and salinity. The TSG does not require additional efforts by the scientific party. TSG data can be viewed graphically using the ship's Scientific Computer System (SCS). The TSG provides very high spatial and temporal resolution measurements of sea surface temperature and salinity of high precision. These data are useful for identifying surface manifestations of fine scale horizontal structures, such as fronts and eddies, along the cruise tracks. These observations also allow for calibration and monitoring of remote sensing of sea surface temperature and salinity.

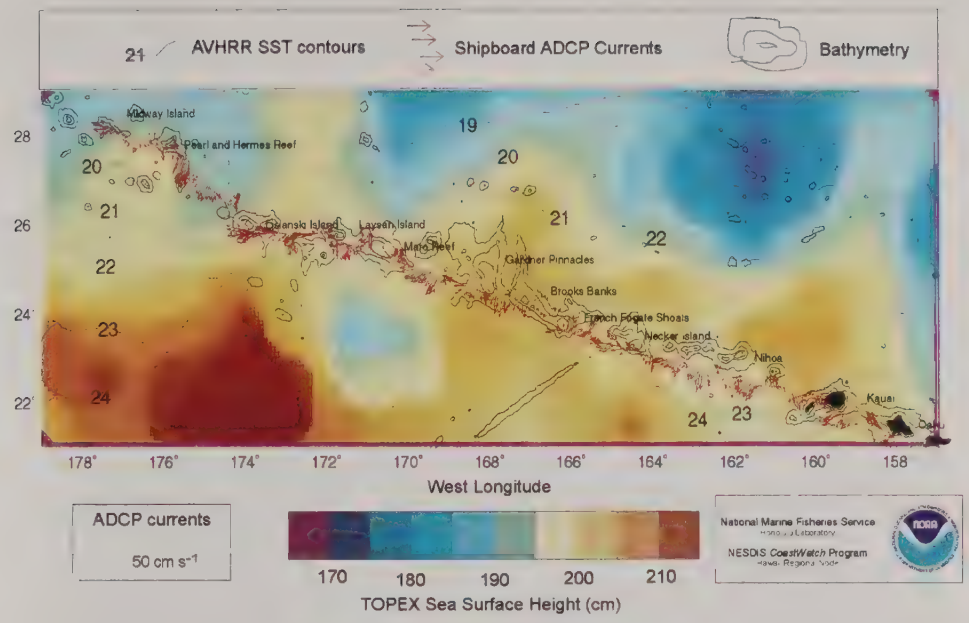

Figure 58. Shipboard and satellite-based data sets are merged to provide an enhanced description of the oceanographic processes along the Northwestern Hawaiian Islands during a cruise of the NOAA ship *Townsend Cromwell* in March 1996. Along track ADCP currents are depicted as red vectors (arrows), satellite AVHRR sea surface temperature isotherms are red contours with black numbering, TOPEX/Poseidon sea surface height is represented by false color shading, and black contours correspond to the bathymetry of the island and banks of the NWHI.

Satellite Remote Sensing

The second major component of the HL insular ecosystem monitoring program is the comprehensive use of available satellite remote sensing information. As discussed in the CoastWatch and Fishery Oceanography sections, satellite remote sensing provides a time series of very good spatial coverage of sea surface height (TOPEX altimeter), sea surface temperature (AVHRR, GOES radiometer), ocean color (SeaWiFS), and surface winds (QuikScat scatterometer) throughout the NWHI ecosystem. This good spatial and temporal coverage of surface conditions allows investigators to observe and monitor large-scale oceanographic processes affecting these insular ecosystems. Combined with the observations of vertical structure from ships and mooring, oceanographers are better equipped to address questions about the complex physical and biological processes. As an example of combining shipboard and satellite observations, Figure 58 demonstrates the merging of shipboard current profiles (ADCP), satellite-based sea surface temperature (AVHRR) and sea surface height (TOPEX/Poseidon), and bathymetry to provide an enhanced description of the oceanographic processes of the NWHI at a particular time (Fig. 58). Similarly, ocean color and surface winds can be merged to examine relationships and interactions between physical and biological processes.

In addition to using satellite remote sensing to examine oceanographic conditions over the extent of the NWHI insular ecosystem, HL and CoastWatch are using these data sets to examine temporal variability by generating time series at specific locations (Fig. 59). These time series are used to examine seasonal, interannual, and even decadal fluctuations of ecosystem conditions and to relate these fluctuations to biological monitoring of monk seals, sea turtles, lobsters, bottomfish, and coral reef species of the NWHI.

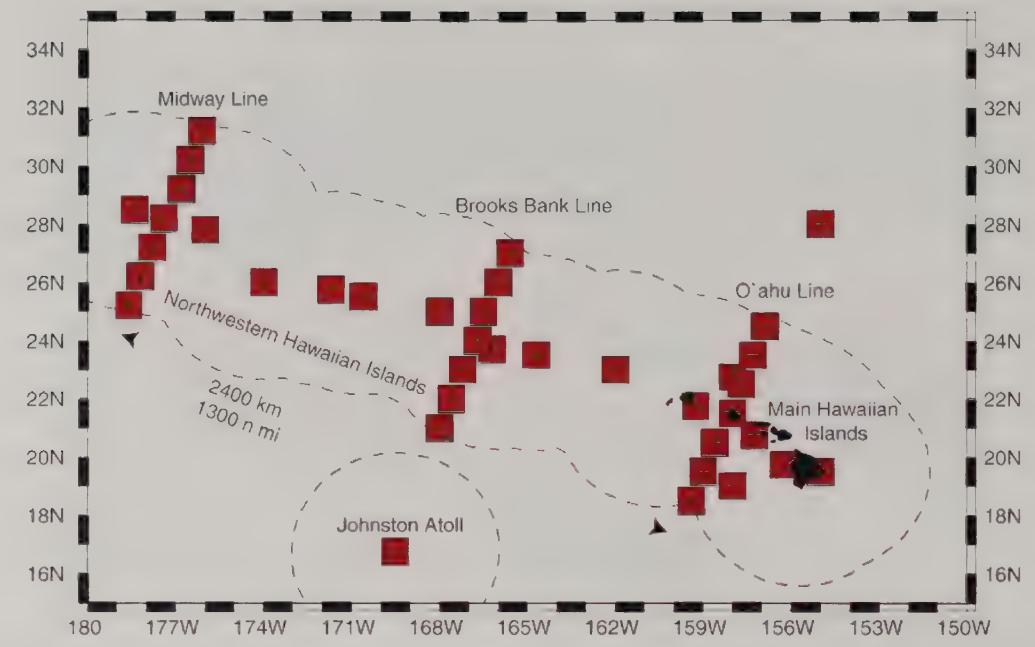

Figure 59. Standardized locations of time series satellite data sets generated by CoastWatch to monitor oceanographic processes in the NWHI ecosystem. Time series have been generated for surface winds, sea surface temperature, sea surface height, geostrophic currents from sea surface height, ocean color, and significant wave height. The duration of these time series varies depending on the satellite sensors.

Oceanographic Moorings

The final major component of HL's insular ecosystem monitoring program is the occasional use of oceanographic moorings to provide very high temporal and vertical resolution observations at specific locations. HL oceanographers, in collaboration with NOAA's Pacific Marine Environmental Laboratory (PMEL) and the University of Hawaii (UH), recovered two subsurface oceanographic moorings in August 1999 that were deployed on the flanks of Southeast Brooks Bank (24°00.3'N, 166°41.7'W) in 67 and 80 m of water, respectively, in August 1998 (Fig. 60). The location of these moorings was selected because it was a known foraging habitat for Hawaiian monk seals, and it is representative of a typical shallow bank habitat of the NWHI lobster and bottomfish fisheries.

The first mooring was instrumented with an Aanderaa TR-7 50 m thermistor string with temperature sensors spaced every 5 m between the depths of 20 and 70 m. Unfortunately, a couple of months into the deployment, water intruded into the electrical conducting cable contaminating the later portion of the temperature data. In addition, six archival fish tags from two vendors (Wildlife Computers and Northwest Marine Technologies) were attached to this mooring to investigate the vertical dependence of the light-level based geolocating algorithms. The results of this work have been submitted for publication and should assist in the development of improved archival fish tags and algorithms.

The second mooring was instrumented with an upward-looking RD Instruments ADCP and a Seabird Electronics SBE26 wave and tide recorder. The ADCP measured ocean currents at a 2 m vertical resolution from a depth of about 10 m above the bottom (70 m) to a depth about 10 m below the surface. Although these data are still being processed and analyzed, velocities were generally eastward at about 25 cm/s throughout the water column over the bank (Fig. 61). An exception was observed during December 1998 through January 1999 when a strong westward current averaging about 50 cm/s was observed over the bank. Preliminary analysis of the wave and tide data time series

(Fig. 62) reveals a complex structure of high frequency wave energy over the summit of Southeast Brooks Bank. It is hypothesized that the strength of the current and the amount of wave energy reaching the summits and flanks are related to the types and amounts of flora and fauna which can inhabit these regions. In other words, these conditions help to characterize the essential fish habitat of these ecosystems.

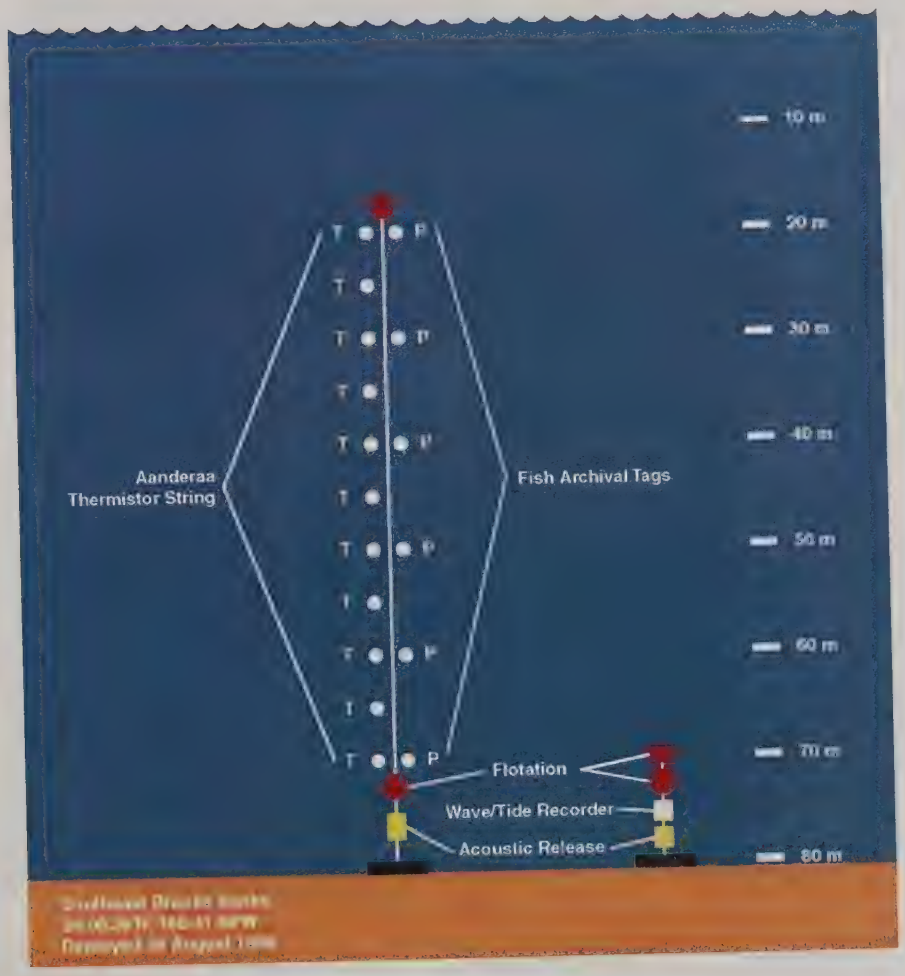

Figure 60. Schematic representation of two subsurface oceanographic moorings deployed in August 1998 on the flanks of Southeast Brooks Bank. The moorings were instrumented with 11 temperature recorders, an acoustic Doppler current profiler, a wave and tide recorder, and 5 archival fish tags.

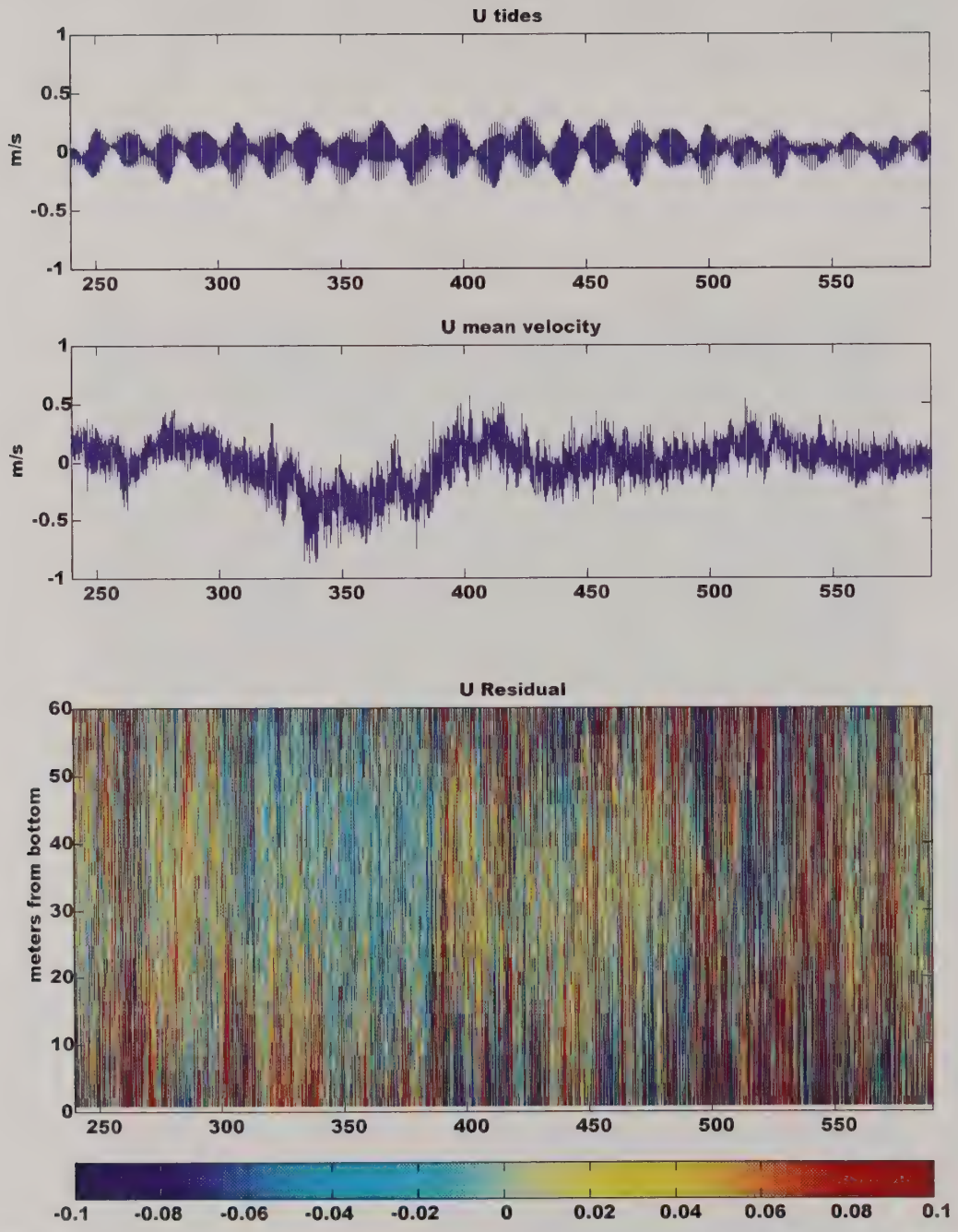

Figure 61. Ocean currents velocities over Southeast Brooks Bank for the period August 1998 until August 1999 recorded using a moored acoustic Doppler current profiler: a) zonal tidal currents (ms^{-1}), and vertical profiles of residual currents after removing tides and depth averaged mean current.

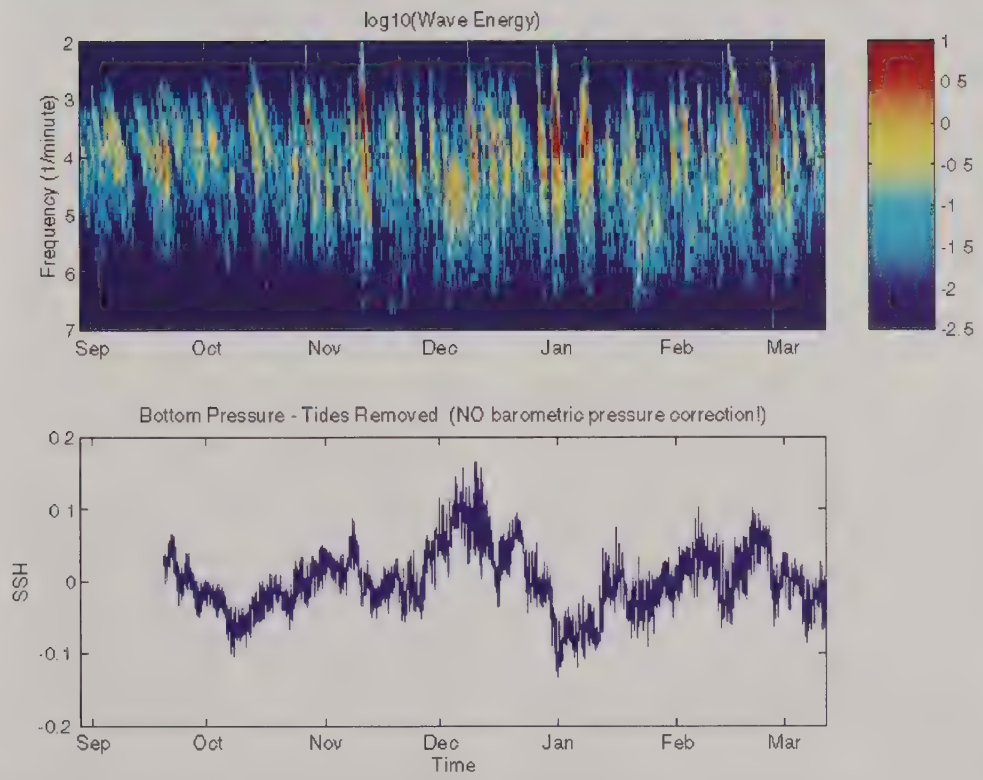

Figure 62. Time series' of a) wave energy (min^{-1}) and b) de-tided sea surface height computed from bottom pressure (m) at Southeast Brooks Bank for the period September 1998 through March 1999.

ESSENTIAL FISH HABITAT

Background Information

The HL is employing an interdisciplinary approach for describing and identifying the essential fish habitat (EFH) of resources covered by FMPs of the western Pacific region. Fishery biology, oceanography, ecology, and geographic disciplines are employed to describe and identify EFH using data derived form remote-sensing, in situ surveys, moored instrument, oceanographic models, and commercial fishery data.

The Magnuson-Stevens Fishery Conservation and Management Act as amended (SFA; Public Law 104-267) establishes a new mandate to identify, conserve, and enhance EFH for all fishery species managed under Federal FMPs. The SFA defines EFH as "those waters and substrate necessary to fish for spawning, breeding, feeding, or growth to maturity." "Waters" include aquatic areas and their associated physical, chemical, and biological properties that are used by fish and may include aquatic areas historically used by fish where appropriate. "Substrate" includes sediment, hard bottom, structures underlying the waters, and associated biological communities. "Necessary" means the habitat required to support a sustainable fishery and the managed species' contribution to a healthy ecosystem. "Spawning, breeding, feeding, or growth to maturity" covers a species' full life cycle.

Goals and Objectives

HL's goal is to describe and identify EFH for central and western Pacific species under FMPs. Objectives include collecting information using advanced aerial, oceanographic, and satellite technologies, integrating the information using modern analytical tools, and providing science-based advice for management.

Major Applications and Research

NWHI Lobster and Bottomfish

The identification and delineation of EFH for lobsters, bottomfish, and other neritic insular species are being enhanced using a variety of new initiatives. These initiatives utilize detailed fishery-oriented field surveys and rapid ecological assessments in combination with aerial and satellite multispectral and hyperspectral imagery to interpolate shallow water contours and substrate. In the proposed 2000 lobster experimental fishery for example, observers on commercial lobster boats will record interactions with coral and other nontarget, neritic taxa.

HL participation in the national coral reef initiative will involve the collection of detailed satellite imagery for selected areas in the Northwestern Hawaiian Islands (NWHI). A lack of well-distributed and representative field surveys will continue to constrain this work. HL is exploring a method of bottom substrate classification that uses interpolated field surveys of substrate and contour ranges in one atoll and applies them as surrogates to similar contour ranges in other atolls. It is possible to do this because a geographically and horizontally accurate bathymetric model of most of the Hawaiian Archipelago, based on data collected using a variety of instruments by the National Ocean Survey, the U.S. Geological Service, the Army Corps of Engineers, Joint Institute for Marine and Atmospheric Research, and NMFS is nearly complete (Fig. 63).

The general development of geographic information system (GIS) applications using observer and *Townsend Cromwell* (*TC*) lobster data continues. Composite data sets for all *TC* cruises from 1978 to 1999 have been constructed in the Oracle database to provide detailed location-referenced samples of species composition, age, size, sex, and reproductive condition. Data sets have also been constructed using observer data from 1991 to1999 that provide location-referenced data detailing number of sets and catch rates by species, as well as samples of size and reproductive condition from commercial catches. These data have been assembled into a variety of GIS layers that have been used by WPRFMC and NMFS managers and researchers to evaluate the geographical distribution of catch, size, sex, and reproductive condition from a geographic and depth distribution perspective. An example of the

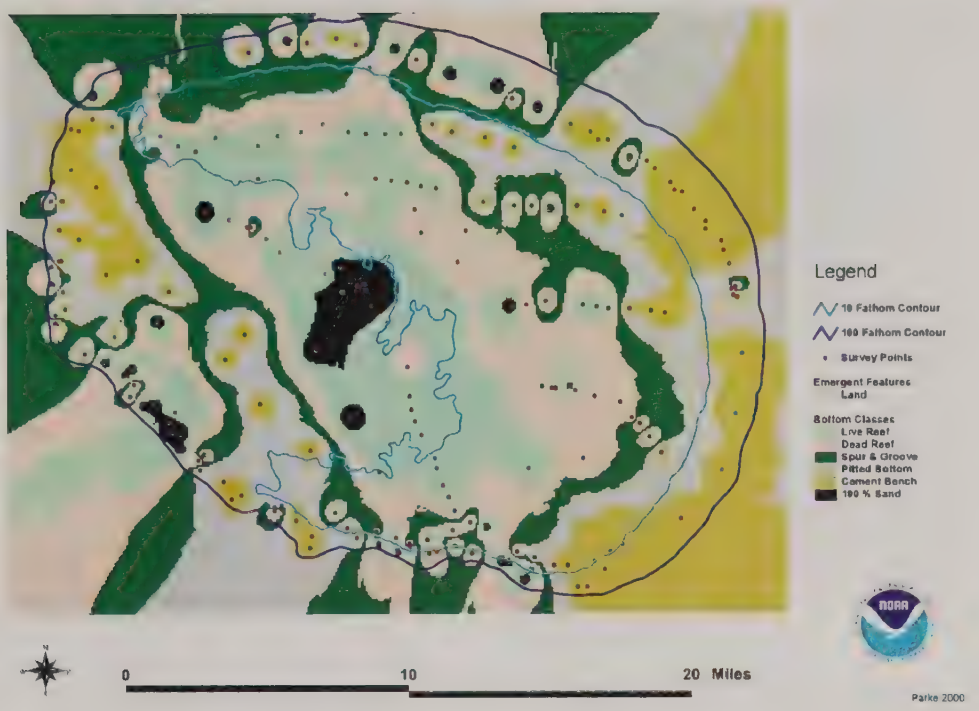

Figure 63. Constructed GIS substrate model of French Frigate Shoals based on search habitat surveys.

type of map product generated is shown in Figure 64 which represents the movement of tagged spiny lobsters trapped and released at Necker Island during1998-99. As the work on bottom substrate characterization progresses, some insight may be provided into the nature of these movements.

Main Hawaiian Islands (MHI) Juvenile Bottomfish Fish Habitat

The cooperative study of the habitat of juvenile bottomfish in the MHI, by HL, the Hawaii Division of Aquatic Resources (HDAR), UH's Hawaii Institute of Marine Biology (HIMB), and the U.S. Fish and Wildlife Service's (USFWS) Cooperative Fisheries Unit scientists continued. This study is made possible by a grant awarded competitively from the Office of Oceanic and Atmospheric Research (OAR), Hawaii Undersea Research Laboratory (HURL). The submersible *Pisces V* was used to revisit sites off eastern Oahu and Penguin Bank in the depth range of 200-400 m. At the Oahu site, gently sloping flats of sand nearly devoid of fish fauna were found in the 200-300 m depth range, whereas juvenile snapper habitat was found between 300-400 m. Juveniles of both onaga and ehu were found associated with small outcroppings of submerged reef (limestone) on otherwise flat sandy bottoms at about 300 m (Fig. 65). Juvenile snappers would usually seek protection in the low relief undercuts when approached by the submersible. Potential prey items, such as *Symphysanodon moanaloae*, were observed at the same 300-400 m sites (Fig. 66). Adult ehu were observed at both sites associated with undercuts and holes on the steeper slopes. Adult and subadult onaga were observed moving in small aggregations above the bottom. Greater numbers of juvenile and subadult snappers were observed on dives in 1999 than in 1998.

Gold Coral/Eels/Monk Seals

Recent plans to commercially harvest deepwater precious corals in the vicinity of

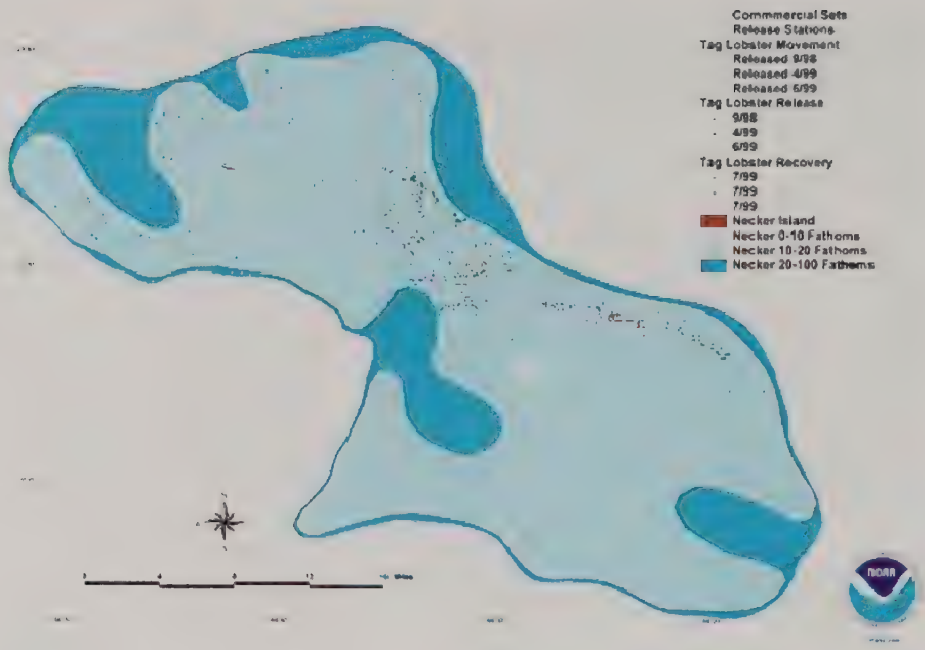

Figure 64. Research lobster tagging and trapping activity during 1998/1999 at Necker, Northwestern Hawaiian Islands.

Figure 65. Juvenile onaga, *Etelis coruscans*, observed in situ at about 300 m depth.

Figure 66. Juvenile onaga observed in situ in same sandy/limestone outcropping habitat, with a prey species *Symphysanodon moanaloae* above its head.

islands populated with monk seals prompted 7 concerns about potential impacts to newly identified seal foraging grounds. A review of movement data from 33 seals fitted with satellite tags at French Frigate Shoals (FFS), identified two areas where seals revisited subphotic depths (>300 m). Submarine surveys were conducted in collaboration with UH, OAR, and HURL with funding awarded competitively. These surveys of the sea floor at each area (n = 2) revealed beds of deepwater coral including species of gold coral (*Gerardia* sp.), pink coral (*Corallium* sp.), and probable monk seal forage species including a deepwater synaphobranchid eel (*Media abyssla*). Previous submarine surveys (n = 12) conducted in search of precious coral

over the wider FFS region at relevant depths found no coral beds, indicating that the seals' targeting of these two areas supporting deepwater corals as preferred forage habitat was not random (Fisher exact probability test, $P = 0.01$). In an attempt to further document seals foraging in the coral beds, five seals were instrumented with a back-mounted video recorder (CRITTERCAM). None of the seals visited subphotic depths. However, three of these seals visited beds of filamentous black coral (*Cirrhipathes* sp.) at moderate depths (80-100 m) where they fed on resident fish. The vertical relief afforded by deepwater coral provides shelter superior to adjacent habitat and thus attracts and supports a fish community. Proposed is an hypothesis that seals frequent these coral beds to feed on their associated fish assemblages and improve overall foraging success.

Subtropical Convergence Research Essential Fish Habitat

Two temporally and spatially dynamic large scale oceanographic features, the Subtropical Frontal Zone (SFZ) and the transition zone chlorophyll front (TZCF), have been identified as EFH for a number of pelagic marine resources including swordfish and sea turtles and the interaction between sea turtles and the fisheries targeting swordfish are of great concern (see sections on pelagic and HMS oceanography). The SFZ is a region of Ekman convergence driven by large-scale ocean surface winds. It is a region where cool, lower salinity, and nutrient rich water to the north converges with the warmer, saltier, nutrient depleted waters to the south. This convergence gives rise to distinctive individual fronts and frontal systems that uniquely influence the abundance and distribution of the various organisms that inhabit the area. Of particular interest are the south subtropical front (SSTF) and STF and the TZCF that specifically have been identified as key habitats for swordfish and loggerhead turtles respectively.

FISHERY MONITORING, DATA MANAGEMENT, AND ECONOMICS

Fishery monitoring is a critical tool in meeting the mission of HL–these operations principally involve the following two programs:

- Federal logbooks and shoreside monitoring, including seafood markets.
- Western Pacific Fishery Information Network (WPacFIN), which compiles island fisheries agency data and provides these agencies with technical assistance.

This information is used for Federal fisheries management in American Samoa and Hawaii and for advice to U.S. negotiators in international management of highly migratory species in the central and western Pacific, as well as for basic biological and habitat research and fisheries statistics and data management assistance to American Samoa, Guam, Hawaii, and The Commonwealth of the Northern Mariana Islands (CNMI) through the WPacFIN cooperative agreement. Information is also shared in various international scientific forums (e.g., the Interim Scientific Committee for Tuna and Tuna-Like Species in the North Pacific (ISC) and the Secretariat of the Pacific Community's Standing Committee on Tunas and Billfish). Increasingly HL staff are involved in the information systems utilized by the NMFS observer programs operated out of Honolulu through the Southwest Region's (SWR) Pacific Islands Area Office (PIAO).

While WPacFIN has been successful in receiving Program, Project, and Activity (PPA) funding supplements over the past several years, the fishery monitoring, data management, and economic programs have been relatively impoverished and increasingly understaffed as responsibilities expand.

FISHERY MONITORING GOALS AND APPROACH

Fishery monitoring goals can be summarized as follows:

- Provide fisheries-dependent data for biological and economic research, including information for ecosystem management, marine habitats, and fisheries interactions with protected species (e.g., marine turtles and sea birds).
- Provide reports on the status of commercial and recreational landings and fishing activities.
- Provide technical support to fisheries agencies in the central and western Pacific.

Domestic fishery monitoring involves the following activities:

- Collecting and processing logbook information for the Hawaii-based longline, the NWHI lobster and the Hawaii precious coral fisheries.
- Developing computer-based data quality control and summarization programs, including the American Samoa domestic longline fishery.
- Issuing quarterly and annual reports on Federally managed fisheries (including longline, bottomfish, lobsters, and precious corals).
- Making the information available to the public in various reports and web pages.

The general approach at HL to fishery monitoring involves NMFS staff contacting fishing vessel captains and operators before and after each fishing trip to provide information important to proper filing of logbooks, species identification, and taking observations the captains may have about fishing conditions and seafood markets. HL staff who collect the logbooks are also involved in shoreside monitoring, data quality control, and report generation. Reports include quar-

terly reports for the longline fisheries and more detailed and descriptive annual reports on the Hawaii longline and NWHI fisheries.

Fisheries research relies substantially on timely access to high-quality fisheries-dependent data. This involves the identification of data needs and ensuring that these data are collected and made available to the appropriate researchers. To accomplish this, data are acquired from or made available by linking to outside sources or are collected directly by HL. It is important to ensure that the quality and quantity of data meet statistical and analytical requirements.

For example, shoreside monitoring provides an independent measure of the validity of logbooks filed by fishing captains. HL's market sampling program has been conducted at the Honolulu auction since 1984. This is the largest public auction for fish and seafood products in Hawaii. It is the central focus for much of the sales activity of the Hawaii longline fleet and the NWHI bottomfish fleet, which fall under Federal management. The landings and sales information gathered provide the baseline for assessing two of the Western Pacific Regional Fishery Management Council's (WPRFMC) four Fishery Management Plans (FMPs): Pelagics and Bottomfish. Although the market monitoring frequency has decreased over the years, the State of Hawaii--with the technical assistance of HL's Western Pacific Fishery Information Network (WPacFIN) program--is taking new steps to acquire information directly from the auction electronically. Information is also obtained electronically by WPacFIN from a variety of other seafood outlets in Hawaii.

Additional sampling outside of the present market monitoring program includes collection of NWHI post-harvest lobster size frequencies (both frozen tail and whole live).

The following fisheries are actively monitored:

- NWHI lobster: Federal logbooks and revenue reports, compiled into an annual report (Pooley and Kawamoto, 1999).

- Hawaii domestic longline: Federal logbook reports issued quarterly and annually (Ito and Machado, 1999), and include information from shoreside monitoring of landings and as a WPRFMC annual report module.

- Hawaii precious coral: Federal logbooks are required of this fishery but at present there is only one operator. As a result, all information on this fishery is confidential. Nonetheless, the logbook data are provided to PIAO for quota monitoring and to HL scientists for stock assessment purposes.

- American Samoa domestic longline: Federal logbooks (collected through the American Samoa fisheries agency in Pago Pago) compiled in quarterly reports. A new reporting system was put in place this year that relies entirely on the American Samoa Department of Marine and Wildlife Resources for data collection, quality control, and reporting.

- NWHI bottomfish: State of Hawaii logbooks and collaborative shoreside monitoring, compiled into an annual report (Kawamoto, 1999) and as a WPRFMC annual report module.

In addition, the following two specialized reports are prepared:

- U.S. landings in the western Pacific for *Fisheries of the United States*, annually, in collaboration with PIAO.

- Fisheries Statistics of the Western Pacific (FSWP), annually prepared by WPacFIN from statistics compiled by fisheries agencies in American Samoa, Guam, Hawaii, and the CNMI. Information from FSWP is also used in preparing the bottomfish and pelagic fisheries annual report for the WPRFMC.

The Hawaii-based domestic longline logbook program is essentially a census

(complete and comprehensive accounting) of trips taken in the fishery because a dockside inventory of vessels operating out of Honolulu can be maintained, although vessels which land in California operate under different rules. Under a data sharing agreement, HL receives both sets of logbooks which are keypunched in Honolulu and maintained in separate data bases. Electronic data files are returned to the California Department of Fish and Game as part of the agreement. Starting late in 1999, the California logbook was discontinued and a new Federal logbook is required of longline vessels (and others) fishing on the high seas out of California. These logbooks are also sent to HL where they are being compiled.

Landings (weights and values) for the Hawaii longline fishery are monitored through shoreside sampling in Honolulu and State of Hawaii commercial catch reports.

The American Samoa *alia* longline logbook program is not directly monitored by HL, but evidence suggested that early logbooks suffered from quality control problems. Because of this and the importance of having a hands-on presence for working with fishing captains (similar to the Hawaii longline program), the American Samoa logs are now collected by the local fisheries agency in Pago Pago. A review of the success of this program will be conducted later in the year, but the first quarterly report was just issued and results look promising.

The NWHI lobster logbook program is also a comprehensive census of trips taken because of the combination of dockside inventory and in-season reporting requirements through the PIAO. In addition, lobster fishing vessel captains are required to file sales reports to NMFS which are compiled by HL staff. The status of the NWHI lobster fishery is reported in an annual HL Administrative Report.

The more distant portion of the NWHI bottomfish fishery has been under a limited entry program requiring Federal permits since the mid-1980s, while the area just north and west of Kauai came under a limited entry program in mid-1999. The NWHI bottomfish data reporting program involves a combination of the Hawaii Division of Aquatic Resources' (HDAR) commercial logbooks and sales reports for the participants and shoreside monitoring by HL and HDAR staff. The status of the NWHI bottomfish fishery is published annually by HL staff and includes an estimate of the optimal number of vessels in the more distant limited entry zone.

Finally, HL and HDAR staff monitor the Honolulu auction on a twice weekly basis with the objective of providing more detailed size sampling and ex-vessel values of the landings. These data are compiled and used in estimating the landings of the Hawaii-based domestic longline fishery and the NWHI bottomfish fishery and in preparing estimates of stock status. Tissue and specialized measurements are also taken by Honolulu Laboratory staff. The NWHI lobster landings are also sampled for size and sex composition on an as-needed basis. There is no adequate sampling of landings on the neighbor islands, but the WPacFIN program has arrangements with a number of seafood dealers to receive sales receipts electronically, and WPacFIN is working with the State of Hawaii's HDAR to implement a statewide seafood dealer reporting system.

WESTERN PACIFIC FISHERY INFORMATION NETWORK (WPACFIN)

Background

In 1981 WPacFIN was initiated as a formal cooperative agreement among fisheries agencies in the central and western Pacific to improve fishery monitoring and reporting systems to better meet local and Federal fishery management needs. The NMFS HL program, known as Central WPacFIN, has strived to develop and implement appropriate and comprehensive data collecting and processing systems in each of the four major WPRFMC island areas: American Samoa, Guam, Hawaii, and the CNMI. Formalizing and standardizing data collecting systems and computerizing the collected data began in the early 1980s. As technology changes, so has WPacFIN's approach. WPacFIN is now

in its third year of implementing major hardware and software upgrades, moving to the Windows 98 and Visual FoxPro environments in all agencies. The legacy systems are being significantly redesigned and improved to take advantage of newer technology and become Y2K compliant, to improve data quality, and to reflect changes in the fisheries and in federal reporting requirements.

Many of the island agency fisheries data collecting systems have also changed to improve fisheries monitoring programs and to begin addressing many of the increased informational needs of the local and federal fisheries management organizations within WPacFIN. Changes have been implemented these past two years to address data needs to meet new SFA and various FMP Plan Team reporting requirements, such as bycatch, fishing sector, charter boat, and recreational fishing data. Plans for implementing more changes are being finalized. The central WPacFIN office assists in identifying these changes and supports the island agencies by developing appropriate data collecting, processing, and reporting systems for the island agencies and helps train the local staff in implementing the changes.

Significance

WPacFIN island agency data systems are the monitoring mainstay of many fisheries in the central and western Pacific and provide data and information for meeting Magnuson-Stevens and Sustainable Fisheries Act requirements. Use of the Internet and development of a WPacFIN web site is improving the availability of WPacFIN data and information.

WPacFIN Goals and Approach

Central WPacFIN

- Coordinates fisheries statistics programs in the region.
- Provides technical computer and biological assistance to island fisheries agencies.
- Provides hardware and software support to these fishery agencies.
- Prepares fishery monitoring and fishery statistics compilation systems, including software development.
- Compiles and disseminates regional fisheries statistics.

Administrative Report H-98-11 (December 1998), *Central Western Pacific Fishery Information Network (WPacFIN) Three-Year Plan*, summarizes the general program areas, support activities, and projects conducted by Central WPacFIN and describes the many system upgrades and changes being implemented in island areas as recommended by the February 1997 WPacFIN Data Workshop 2000.

RECENT FISHERY MONITORING ACTIVITIES

Hawaii Longline Logbook Reporting

Laboratory staff continue to upgrade the quarterly and annual reports on Hawaii domestic longline fishery data system to make the information more accessible and more complete. Staff have also worked with various fishing vessel captains on prototypes of electronic logbooks and have experimented with receiving logbook data through email. Summaries of the Hawaii logbook data are now available on HL's web site, and 5-degree square (nonconfidential) data are downloadable from the following HL web site: http://www.nmfs.hawaii.edu/fmpi/fmep/index.htm.

Hawaii Longline Enforcement Cooperation

HL staff have been working with NMFS Southwest Enforcement in cross-checking logbook numbers with off-loadings in Honolulu Harbor. HL have trained Enforcement staff in species identification and have participated in monitoring a sample of off-loadings. This cooperative effort between Enforcement and HL has already had a noticeable effect in

improving the quality of the marlin species identifications, the count of secondary species, and the recording of shark fins.

Statistical Analyses of Hawaii Longline Catch Rates and Catch Composition

For the past 2 years statistical analyses have been conducted comparing the logbooks of Hawaii-based commercial longline vessels and records kept by NMFS fishery observers to identify the normal variation between the two reports as a baseline for enforcing logbook record-keeping for nonobserved trips.

The results from this research were published in SWFSC Administrative Report H-00-07. Catch records for 15 fish taxa were compared from 2,684 longline sets (1994-98). The report analyzed exact concurrences (logbook = observer report numbers) as well as means and other statistical measures of comparison. For target species the rates of exact concurrence were quite high, up to 96%, while for incidental species they lagged considerably. Deviation from exact concurrence for incidental species was usually related to the total number of a species caught, In some cases the problems could be linked to individual fishing captains. In other cases, there were more systemic problems. For example, rounding catch numbers by captains filing logbooks was found to be a particular problem for blue shark, while species identification was a problem for the marlins. In most cases, the differences are less than 1-2 fish per set and in almost all cases there is minimal impact of these "discrepancies" on the mean catch-per-unit-effort (CPUE). In addition, a simple statistical procedure has been identified for filtering these errors, which will make development of research data bases much easier, allowing more timely analyses.

New Longline Fishery Monitoring System in American Samoa

The pelagic longline fishery in American Samoa has grown steadily since it began developing in earnest in 1995. The logistics of monitoring this fishery from Hawaii using the Federal logbooks proved to be a formidable task for processing, validating, and quality controlling the data submitted by the fishermen. The WPacFIN program worked with the Department of Marine and Wildlife Resources (DMWR) to implement a new monitoring program to be conducted using DMWR staff, partially funded through WPacFIN. By July 1999 the first phase of the monitoring program, the Daily Effort Census was implemented. This involves 6-days-a-week dockside validation of the status of each longline-permitted vessel which is later used to cross-check the submitted logbook to ensure full compliance. In January 2000 the most critical remaining parts of the monitoring system were implemented. These included a computerized data processing system to process and quality control all logbook data at the local level. This has increased the timeliness and accuracy of the data through improved data handling and quality control procedures. Because of the local processing capabilities, logbooks can be reviewed and discrepancies resolved with the fishermen within days of submission. Quarterly reports for the fishery are now filed by DMWR.

New Boat-based Creel Survey System in Saipan, CNMI

In response to recommendations from the WPRFMC and its advisory bodies, the WPacFIN's Fisheries Data Coordinating Committee-approved allocation of WPacFIN funds to the CNMI's Division of Fish and Wildlife (DFW) to implement a new boat-based creel survey program on Saipan to improve their overall fisheries monitoring programs and address new Sustainable Fisheries Act (SFA) data requirements. WPacFIN staff designed a pilot project that was implemented in mid-1999 to obtain current data on fishing patterns and participation levels, and results from this survey were then used to design the full-blown creel survey. The new survey was implemented on Saipan in April 2000 and is ongoing. It has specific provisions for obtaining improved data on charter boats, recreational fishing, and bycatch for all boat-based fisheries. WPacFIN also expanded fisheries monitoring programs

in the CNMI to the islands of Tinian and Rota.

DATA MANAGEMENT

Web-based Data Entry for PIAO Observer Programs

Laboratory programmers, in conjunction with SWR Observers from PIAO, developed data entry systems for both Longline and Lobster Observer data sets. These are Web-based ORACLE data entry systems that for the first time allow Observers to enter commercial fishing data from a remote site (PIAO) directly into the ORACLE database residing at HL (Fig. 67). Data entry screens were created for two lobster data sets (catch and effort and morphometrics) and 11 longline data sheets (including catch and effort, morphometrics, and protected species observations). These systems also perform basic data validation and can generate data summaries and reports.

Implemented an On-line Data Directory System (DDS)

Providing easy access to improved documentation for HL data archives has been a long-term goal for Fishery Data Management Program (FDMP). The new DDS is a Web-based Intranet application that provides HL data users with on-line access to significantly improved documentation on HL's major data sets, with more data sets added to its catalog on an ongoing basis. Users can use Netscape Navigator or Internet Explorer to locate documentation on data sets pertinent to their needs. The DDS provides authorized users with descriptions of the data sets, record formats, data codes, images of forms used to collect the data, and other relative metadata (Fig. 68).

New Methods for On-line Query and Access to Oracle Tables

Two alternative tools were developed to provide authorized users with direct access to the more than 50 Oracle tables which FDMP has now loaded into the Oracle database. The first is an extension of the Web-based DDS and links users to Oracle forms which FDMP staff developed for each of the Oracle tables. Each form provides direct access to an Oracle table and allows the user to browse, query, and download selected data for analysis or reporting purposes. Now with these integrated tools, the user can obtain access to all of the documentation for the Oracle data sets and then link directly to the Oracle table as needed (Fig. 69).

The second method of obtaining direct access to the data in the Oracle tables is using a new Web-based JAVA application developed by UH computer science students as a class project. The FDMP Data Manager worked with a team of students to develop this versatile and user-friendly access and query tool which also allows users to browse, query, and download data for analysis and use. The very significant benefit of this JAVA application is that it is a generic tool for accessing any Oracle table and therefore eliminates the time-consuming and arduous task of creating Oracle forms for each table in the Oracle database.

A prototype Web-based data access system that utilizes user passwords to control access levels and privileges was also prepared for access to these data. Standard queries and data summaries are planned for development. To date, a query for longline catch data was implemented to provide data by date and 5-degree squares (Fig. 70).

ESDIM Data Rescue

The ESDIM Data Rescue Project was first funded in FY 1999 in order to electronically capture HL historical data in their original paper format before permanent deterioration of the paper records occurs through the ravages of time, weather, and insects. This is allowing storage of these records as images on disk and transfer of all original paper files to the National Archives.

Substantial progress has been made in identifying and cataloging historical data sets, creating standardized data set documentation, and sorting/cleaning the paper files. Progress was also made by the contractor to develop the necessary image management software and customize it to our require-

ments. Production scanning started in May of 2000 and will continue throughout the next 2 years.

ECONOMIC RESEARCH AND ANALYSIS

Objectives and Approach

The Honolulu Laboratory's economic research and analysis objectives are to:

- Conduct baseline research on commercial and recreational fishing, seafood marketing, and related marine activities in the central and western Pacific.
- Provide analysis for fishery and protected species management decision making.
- Investigate alternative fishery and protected species management regimes for possible actions.

Background Information.

Economic research at the HL over the past 5 years has concentrated on two areas:

- Pelagic fishing vessel economics.
- Theoretical and applied research on alternative fishery management regimes.

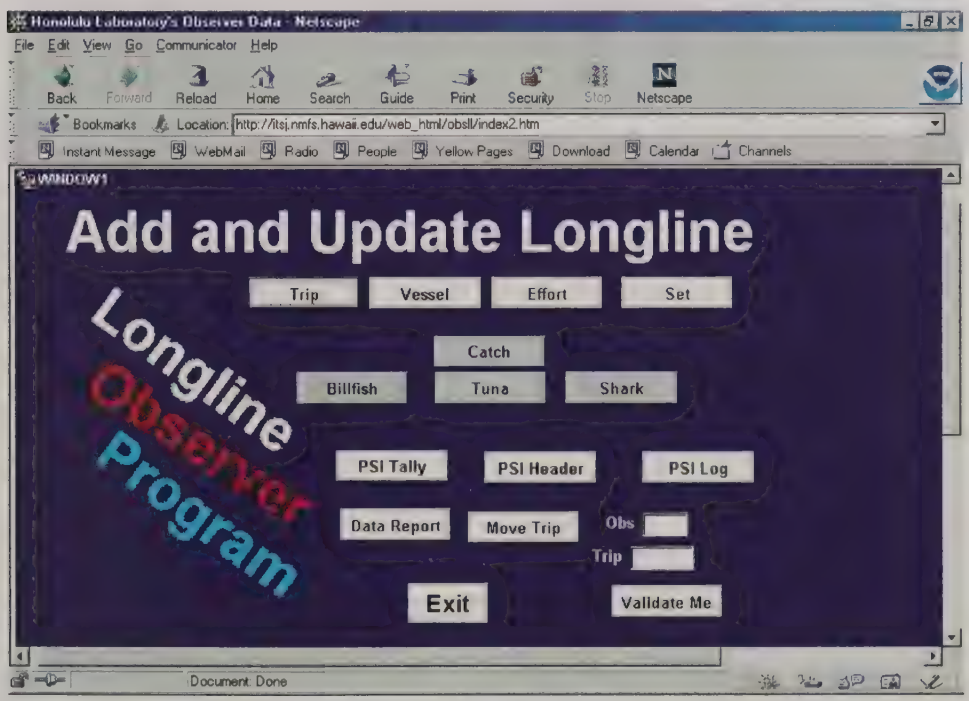

Figure 67. Longline observer Oracle data entry screen.

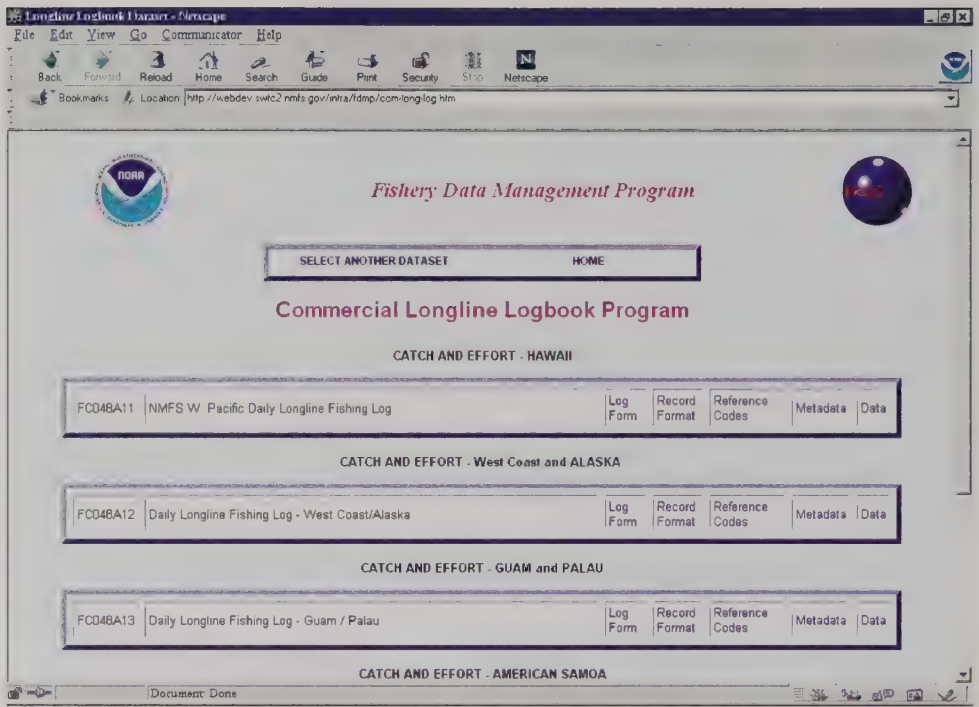
File Edit View Go Communicator Help
Back Forward Reload Home Search Guide Print Security Stop Netscape
Bookmarks Location http://webdev.swfc2.nmfs.gov/intra/fdmp/com-long-log.htm
Fishery Data Management Program
SELECT ANOTHER DATASET
HOME
Commercial Longline Logbook Program
CATCH AND EFFORT - HAWAII
FC048A11
NMFS W Pacific Daily Longline Fishing Log
Log Form
Record Format
Reference Codes
Metadata
Data
CATCH AND EFFORT - West Coast and ALASKA
FC048A12
Daily Longline Fishing Log - West Coast/Alaska
CATCH AND EFFORT - GUAM and PALAU
FC048A13
Daily Longline Fishing Log - Guam / Palau
CATCH AND EFFORT - AMERICAN SAMOA
Document Done

Figure 68. Fishery Data Management Program data catalog on-line screen.

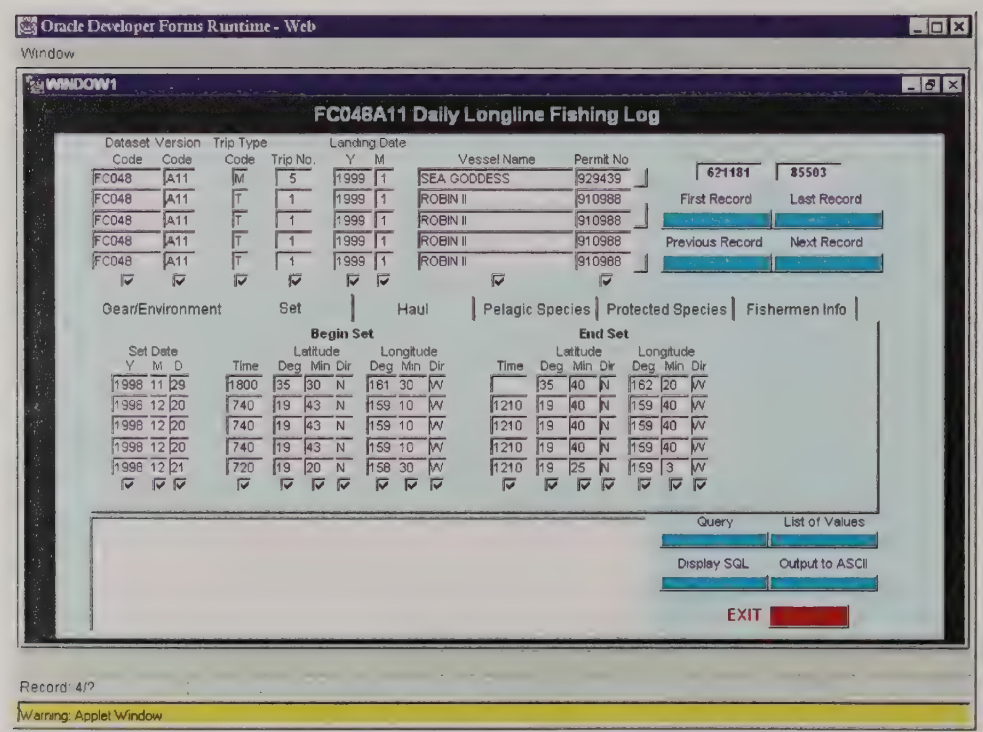
Oracle Developer Forms Runtime - Web
Window
WINDOW1
FC048A11 Daily Longline Fishing Log
Dataset Code
Version Code
Trip Type Code
Trip No.
Landing Date Y
M
Vessel Name
Permit No
FC048 A11 M 5 1999 1 SEA GODDESS 929439
FC048 A11 T 1 1999 1 ROBIN II 910988
FC048 A11 T 1 1999 1 ROBIN II 910988
FC048 A11 T 1 1999 1 ROBIN II 910988
FC048 A11 T 1 1999 1 ROBIN II 910988
621181
85503
First Record
Last Record
Previous Record
Next Record
Gear/Environment
Set
Haul
Pelagic Species
Protected Species
Fishermen Info
Begin Set
End Set
Set Date Y M D
Time
Latitude Deg Min Dir
Longitude Deg Min Dir
1998 11 29 1800 35 30 N 161 30 W 35 40 N 162 20 W
1998 12 20 740 19 43 N 159 10 W 1210 19 40 N 159 40 W
1998 12 20 740 19 43 N 159 10 W 1210 19 40 N 159 40 W
1998 12 20 740 19 43 N 159 10 W 1210 19 40 N 159 40 W
1998 12 21 720 19 20 N 158 30 W 1210 19 25 N 159 3 W
Query
List of Values
Display SQL
Output to ASCII
EXIT
Record: 4/?
Warning: Applet Window

Figure 69. Longline logbook on-line data review screen.

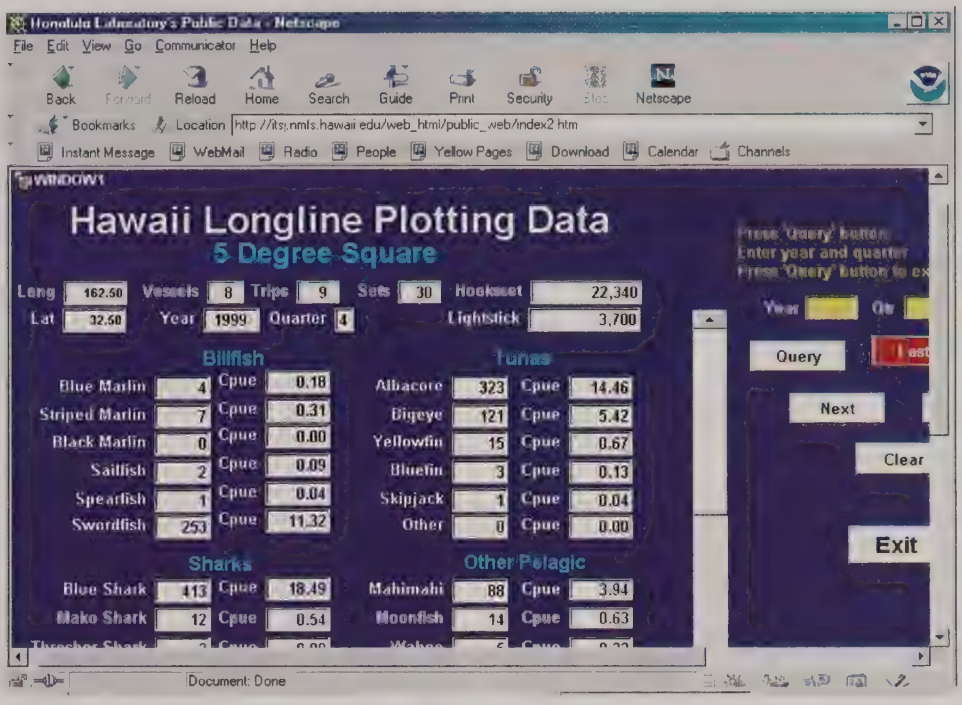
Honolulu Laboratory's Public Data - Netscape
File Edit View Go Communicator Help
Back Forward Reload Home Search Guide Print Security Stop Netscape
Bookmarks Location http://itsnmfs.hawaii.edu/web_html/public_web/index2.htm
Instant Message WebMail Radio People Yellow Pages Download Calendar Channels
WINDOW1
Hawaii Longline Plotting Data
5 Degree Square
Long 162.50 Vessels 8 Trips 9 Sets 30 Hookset 22,340
Lat 32.50 Year 1999 Quarter 4 Lightstick 3,700
Billfish
Blue Marlin 4 Cpue 0.18
Striped Marlin 7 Cpue 0.31
Black Marlin 0 Cpue 0.00
Sailfish 2 Cpue 0.09
Spearfish 1 Cpue 0.04
Swordfish 253 Cpue 11.32
Tunas
Albacore 323 Cpue 14.46
Bigeye 121 Cpue 5.42
Yellowfin 15 Cpue 0.67
Bluefin 3 Cpue 0.13
Skipjack 1 Cpue 0.04
Other 0 Cpue 0.00
Sharks
Blue Shark 413 Cpue 18.49
Mako Shark 12 Cpue 0.54
Other Pelagic
Mahimahi 88 Cpue 3.94
Moonfish 14 Cpue 0.63
Year Qtr
Query
Next
Clear
Exit
Document: Done

Figure 70. Oracle web access to longline plotting data.

Economic Research and Analysis

Economic research and analysis focuses on supporting WPRFMC FMPs. This provides an integrated platform for HL's work. However, new baseline research has been severely reduced by the lack of a NMFS assistant economist and turnover in Joint Institute for Marine and Atmospheric Research (JIMAR) economics staff as well as by ongoing demands under the fishery interaction litigation.

With the demise of the Southwest Region/Southwest Fisheries Science Center (SWR/SWFSC) socioeconomic research fund in the early 1990s due to budget constraints, all quantitative economic research at HL has been conducted in cooperation with UH/JIMAR's Pelagic Fisheries Research Program (PFRP). The Hawaii Fleet Industry and Vessel Economics project (HIFIVE) has conducted a range of field investigations on the cost-earnings structure of the Hawaii-based domestic longline fishery as well as the Hawaii small boat pelagic fisheries, including trolling, handline, charter boats, and charter fishing patrons. Economic analysis on NWHI lobster and bottomfish issues has relied on data collected in the mid-1980s and early 1990s, respectively.

Regulatory Flexibility Act–The Regulatory Flexibility Act of 1996 (RFA) is the primary legislation driving economic analysis in the current period. It allows judicial review of agency assessments concerning the economic impact of regulations on small businesses, non-profits, and local governments. The NMFS Office of Sustainable Fisheries (F/SF) has initiated efforts to revise NMFS' guidelines on complying with RFA requirements (the HL's industry economist participates in that working group). In the meantime, however, F/SF has required a greater degree of specificity in terms of identifying the viable alternatives to be considered by the Council and analyzed under RFA. A PIAO economist has been concentrating on

the former,[1] while HL has been concentrating on conducting simplified pro forma financial statement analyses for the latter.[2] However the analyses of regulatory impacts is increasingly based on older cost-earnings information. Present staff and field work resources are simply inadequate to meet the economic data collection requirements of the revised Magnuson-Stevens Act and the RFA requirements. In addition, extensive turnover in hiring economists through UH/JIMAR has further hampered these efforts.

HIFIVE Activities–The Hawaii Fleet Industry & Vessel Economics project (HIFIVE) is part of the University of Hawaii's JIMAR Pelagic Fisheries Research Program and has been funded since program initiation in 1994 under the co-leadership of HL's industry economist. The purpose of this research project has been to provide fishery management information based on the economic characteristics and dynamics of the Hawaii longline and troll-handline and charter fishing fleets, as well as the seafood markets and clients of the charter-boat fleets. HIFIVE has completed quite thorough field studies on the economics of operations for longline (1993 base year), small-boat troll (1996 base year), and charter boats (1997 base year) in Hawaii (these have been published as JIMAR reports).

Progress in 1999-2000 has centered on two areas as a continuation of work begun early in 1999: the charter boat segment of the domestic pelagic fishery and the local market for pelagic species.

The charter boat segment includes two parts--information on charter fishing patron expenditures and motivations, and patron's self-valuation of their charter boat fishing experience. Over 250 charter boat fishing patrons have completed a voluntary self-administered instrument and additional samples are expected this summer. The charter boat patron research was led by a cooperating JIMAR sociologist. An interim report was completed early in the year and circulated to the Council's Recreational Fisheries Task Force and charter boat captains. This research will be completed once the sociologist position is refilled.

Progress on the pelagic seafood market includes completion of a paper on factors affecting prices using HDAR commercial catch reports. The paper found robust results for particular species, as well as substitution effects between several related species. The analysis was used in this litigation concerning Hawaii longline interaction with sea turtles (Table 9).

Progress on longline and small-boat fishery dynamics was limited to developing time-series necessary for measuring fishing capacity using NMFS standard definitions (the Data Envelope Analysis method). This work will proceed once the JIMAR position is refilled. PIAO is taking the lead on developing qualitative indices of fishing capacity.

Other–The Laboratory's industry economist and JIMAR cooperating economics researcher were co-authors of a number of papers deriving from the JIMAR PFRP research projects of which Dr. Ping Sun Leung of UH's Department of Agricultural and Resource Economics was principal investigator.

Additional economic analysis was conducted in connection with the two lawsuits facing the agency—longline-turtle and NWHI lobster and bottomfish-monk seal—and for providing the analysis required of all fishery management actions under the Regulatory Flexibility Act. In addition the HL economist provided substantial input to the Environmental Assessment on the conduct of pelagic fisheries in the central Pacific and provided Army Corps of Engineers with an update of fishing conditions out of Kahului, Maui for a possible launching ramp and moorage im-

[1]Identification and analysis of alternatives are likely to expand in importance to include broader biological and ecological analysis by HL scientists under National Environmental Policy Act (NEPA) regulations.

[2]These analyses are likely to require Center director certification as are other HL contributions to the WPRFMC process as greater emphasis is placed on the administrative record behind Council decisions (as exemplified by the concerns about the overfishing definitions under SFA amendments).

provement project.

HL's economist also serves on various dissertation committees at UH and serves as affiliate graduate faculty in the departments of Natural Resources and Environmental Management, Political Science, Sociology, and the University's new Center on Globalization.

Table 9. Demand function of bigeye by ordinary least squares estimation, monthly data, 1994-96.

	Coefficient	t Statistic
Constant	11.649	4.603*
Bigeye landings (1,000 lb)	-0.0010	-1.829**
Yellowfin landings (1,000 lb)	-0.0024	-3.688*
Aku landings (1,000 lb)	-0.0030	-2.133*
Sea surface temperature	-0.3062	-2.974*
No. of east-bound visitors	0.0067	1.846**
R^2 adjusted	0.554	
DW-value	1.234	
Observations	36	

HAWAIIAN MONK SEAL RESEARCH PROGRAM

Background And Objectives

The goal of the Hawaiian monk seal research program is to enhance recovery of the critically endangered Hawaiian monk seal population.

Major objectives of the program are to

- Monitor and assess the six main monk seal reproductive subpopulations on the NWHI.
- Study the ecology, biology, and natural history of the Hawaiian monk seal.
- Investigate and mitigate factors impeding the recovery of this critically endangered species.

The Hawaiian monk seal is the only endangered marine mammal residing entirely within U.S. waters, and its future is in grave jeopardy. Beach counts (a historical index of abundance) have declined by 60% since the late 1950s, and 4% to 5% annually from 1985 to 1993. Counts stabilized from 1993 to 1999 (Fig. 71) but will likely continue to decline in the near future due to high juvenile mortality and low reproductive recruitment at FFS, the largest of the six main NWHI reproductive subpopulations. In 1976, the species was designated as depleted under the Marine Mammal Protection Act and listed as endangered under the Endangered Species Act. Although the population remains at critically low numbers, the recent stabilization of population trends has been facilitated by mitigation efforts to enhance survival of females and by natural recruitment.

Elements influencing population growth vary by reproductive site. Naturally occurring

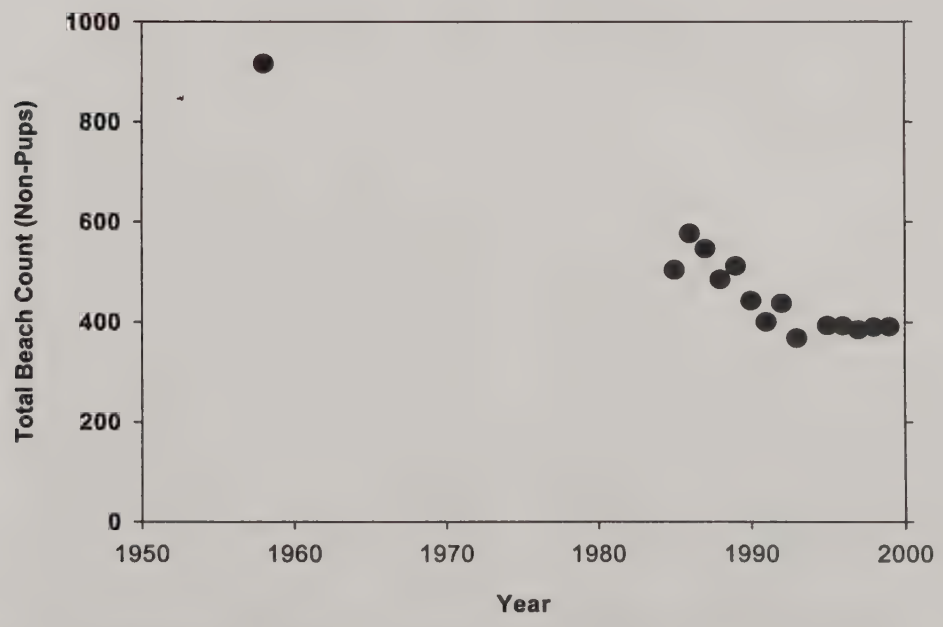

Figure 71. Historical trend in total beach counts (non-pups) of Hawaiian monk seals at the six main reproductive subpopulations.

factors that have or may impede population growth include shark predation, male aggression toward adult females and immature seals of both sexes, habitat degradation due to storms and high seas, disease, and reduced prey availability. Anthropogenic factors that have limited population growth include entanglement in marine debris and human disturbance.

The Hawaiian Monk Seal Program has identified four critical elements for the recovery and conservation of the endangered Hawaiian monk seal: Population Assessment, Foraging Ecology, Health and Disease Assessment, Documentation and Mitigation of Impacts, and Public Outreach and Education. The need to implement all of these high-priority projects is consistent with the recommendations of the Hawaiian Monk Seal Recovery Team (HMSRT), the Marine Mammal Commission (MMC), the Southwest Fisheries Science Center (SWFSC), and the Marine Mammal Recovery Program (MMRP) of the Honolulu Laboratory (HL).

Funding for the recovery of the Hawaiian monk seal program was generally about $500K or less prior to 1994. Beginning in FY 1995 funding was increased by NMFS add-on funds awarded through a competitive process and funds were added to the base. In FY 2000, funding for the program reached its highest level at $1,991K .

Population Assessment and Monitoring

Population assessment and monitoring is a critical and ongoing project at all main reproductive locations–French Frigate Shoals (FFS), Laysan (LAY) and Lisianski (LIS) Islands, Pearl and Hermes Reef, and Midway (MID) and Kure (KUR) Atolls. Research efforts focus on assessing population abundance, trends, survival, and age/sex composition. This research is essential for identifying sites where population growth is limited and for assessing consequences of mitigation efforts to enhance population growth. Data from this work are also required for population modeling to predict the outcome of possible management strategies designed to enhance the recovery of the species. Assessment activities were initiated in the early 1980s, and progress to date has been extensive, with many successes.

Current abundance of Hawaiian monk seals is estimated to be approximately 1,300-1,400. This figure is arrived at in the following way: all individual seals identified in a given year at the six main subpopulations are summed. To this are added estimates of the relatively small number of animals at Necker Island, Nihoa Island, and the main Hawaiian Islands (MHI). These estimates are based on relatively scant data available from comparatively small population centers. In recent years, the total abundance estimate has been slightly more than 1,400 individuals, 90% or more of which are typically counted at the six main breeding subpopulations. Because the total of seals identified is tallied after nearly all pups are born, it is recognized that at any given time throughout the year, total abundance will be reduced by natural mortality, especially among young of the year (YOY). Recognizing this, 1,300-1,400 is a reasonable estimate of total abundance.

Trends in Subpopulation Growth

The primary indices of historical population abundance trends at each of the six main reproductive subpopulations are beach counts. Beach counts consist of the average annual number of seals on the beach during censuses. The censuses consist of timed, standardized counts during which an entire island or atoll is surveyed for seals. Identified individuals are counted only once during the survey. The resulting counts do not reflect total population size but provide an index of population size collected consistently among years and locations. Data collected on each seal observed during censuses include size class (pup, juvenile, subadult, or adult), sex, island location, body condition (a subjective estimate; e.g., fat or thin), individual identity, and molt status. Single atoll-wide censuses at locations with more than a single island (FFS, PHR, MID, and KUR) are completed within a 2-day period. Recent trends in beach counts are shown in Figure 72.

Individual Identification

Throughout the field season, individual seals are identified by plastic tags, bleach-marks, scars, or natural markings. After weaning, pups are tagged on each hind flipper with colored plastic tags uniquely coded to indicate island or atoll population, year of birth, and individual identity. In addition, PIT tags are implanted subcutaneously in the dorsum of most weaned pups.

Colored plastic Temple Tags have been applied to nearly all weaned pups since the early 1980s. Since 1991, PIT tags have also been implanted in the ankle (1991) or the dorsum (all subsequent years) of most weaned pups. Older seals, which were never tagged previously or have lost or broken tags, are opportunistically tagged with both plastic flipper tags and PIT tags. Seals are also bleach-marked for individual identification at all sites except FFS, where bleaching the entire population of seals has been impractical until recently. At LAY and LIS, nursing pups are also bleached prior to molt. Tags, scars, natural markings, and any applied bleach marks are sketched on an individual scar card, which is revised throughout the field season to maintain a current description of the identifying marks of each seal. Photographs of scars and natural markings are added to individual identification files begun during the early 1980s.

Population Size

Population size and composition are determined at locations where all seals have been identified (i.e., observers no longer encounter unidentified seals). These statistics included all individuals seen alive at the location during March through August and parturition status data of females and their pups. If a seal is observed at more than one location during March-August, it is assigned to only one population total according to standardized criteria.

Identification of all individuals is the preferred method for monitoring population trends, and this is the goal for all subpopulations. However, given that identification

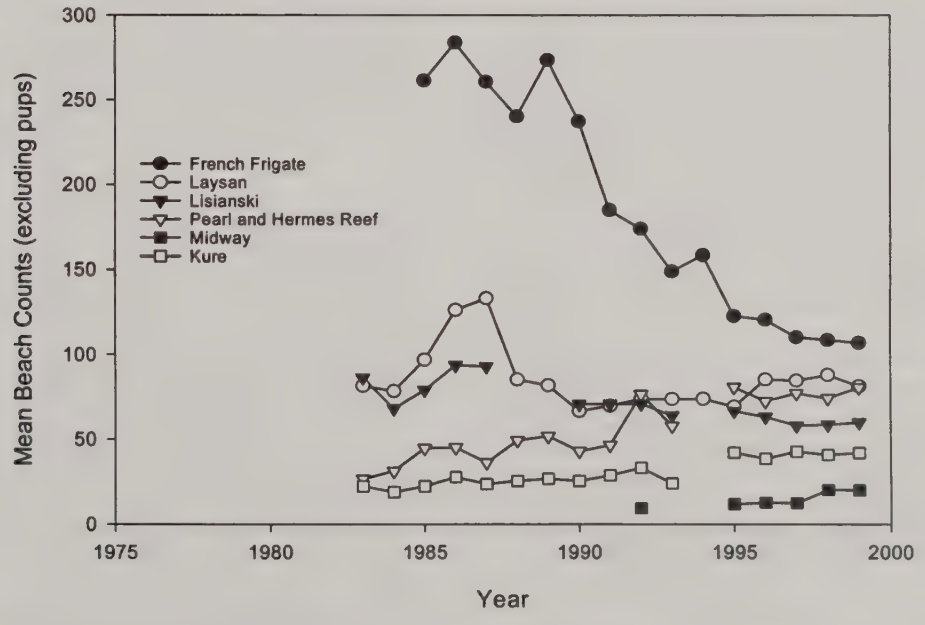

Figure 72. Recent trends in beach counts (non-pups) of Hawaiian monk seals at each of the six main reproductive subpopulations.

effort has until recently been spatially and temporally variable, beach counts remain the most accurate way to assess historical trends in population abundance.

In 1999, the overall trend in abundance of monk seals in the NWHI remained stable. Juvenile survival at FFS and LIS increased, while rates at other sites remained consistent with previous years. The number of pups that weaned and were tagged at FFS in 1998 (n = 88) was higher than in any other cohort since 1989, due in part to the translocation of two aggressive males from FFS to Johnston Atoll. Fortunately, this cohort also had improved survival from tagging to age-1 (53% compared to 14% for the 1997 cohort) (Fig. 73).

The total number of pups born at the six main reproductive subpopulations remained relatively high (243), with more born at LAY (58) and LIS (33) Islands than in any previous year on record. Unfortunately, while the number of pups born at FFS in 1999 was typical, high losses, most probably due to shark predation near Trig and Whaleskate Islands, have already seriously reduced this cohort.

Reproductive Rates

Parturient females are identified, as above, and birth and weaning information is recorded. Because parturient females occasionally foster pups other than their own, efforts are made to identify pups and document changes in nursing relationships from birth to weaning. Pup fostering occurs when two lactating females exchange pups or when a lactating female suckles multiple pups. Consistent field effort to determine age-specific reproductive rates is available from LAY and FFS, and to a lesser extent, LIS. At PHR and KUR, many pups are already weaned when logistics necessitate deployment of research camps so that the identity of mothers is largely unknown. Until recently, few pups have been born at MID. However, currently virtually all mothers at that site are identified.

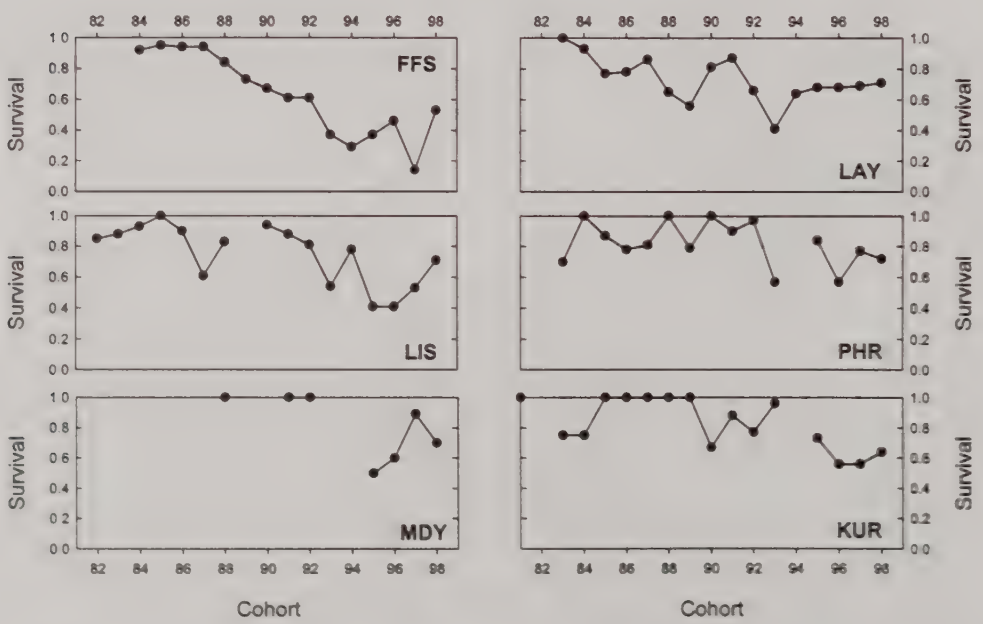

Figure 73. Survival of Hawaiian monk seals from weaning to age 1 year at the six main reproductive subpopulations.

Survival Rates

Identification of individual known-aged seals on an annual basis allows for estimation of age- and cohort-specific survival rates using standard Jolly-Seber estimation methods. The probability of resighting an individual seal at some time during a field season given that seal is alive (i.e., the sighting probability, p) is typically greater than 90% for all ages and locations. In addition to annual survival rates, survival of pups from birth to weaning is also monitored.

Factors that influence survival of individual seals are also recorded. These include injuries from conspecifics, large sharks, etc. Injuries are documented according to standardized categories of severity. Entanglement in marine debris, emaciation, and certain male mounting events are recorded as potentially affecting survival. A seal is considered dead if its carcass is observed. A seal is listed as probably dead if it sustains severe injuries or is emaciated (with skeletal structure clearly evident) and subsequently disappears. In addition, to place a seal in the probably dead category, observation of the individual in a deteriorating or moribund condition is required. Nursing pups were listed as probably dead if they disappeared within 3 weeks of birth. Survival from weaning to age-1 for the main reproduction populations is shown in Figure 73.

Trends in Weaned Pup Girth and Length

Straight dorsal length and axillary girth of weaned pups were measured as soon after weaning as possible to determine pup condition. In particular, the girth of pups at weaning provides a measure of the ability of mothers to provision pups for growth and with energy stores. This, in turn, is used as an indicator of prey availability to pregnant females. Only pups known to have been measured within 2 weeks of weaning are included in analysis of trends in pup condition among sites and over time (Fig. 74).

Trends in weaned pup girths continue to increase in the eastern populations (FFS, LAY, and LIS) and have shown little change in the remaining populations to the west (Fig. 74).

Future Research Related to Population Assessment

Plans for the future include an annual assessment of each reproductive subpopulation by determining abundance, age and sex composition, survival rates, natality rates, migration, sources of mortality, reproduction, growth and condition of seals, behavior, haul-out patterns, and migration. A summary will be reported in a draft NOAA Technical Memorandum which will be intensively reviewed at the annual HMSRT meeting and the results from a 1999-2000 pup survival study at FFS will be reported. Also, an evaluation of the effectiveness of various recovery and conservation measures (e.g., removing sharks and aggressive males, translocating weaned pups from FFS, normalizing sex ratio at LAY to reduce mobbing will be determined at each appropriate reproductive location. Finally, the first full aerial survey for monk seals in the MHI is scheduled for FY 2000.

Foraging Ecology

Monk seals spend up to two-thirds of their lives at sea, but little is known about their foraging patterns and pelagic distribution. Studies of their foraging ecology are essential for the conservation and protection of prey resources and aquatic habitat utilized by this highly endangered species. The primary focus of this research is to improve our understanding of the potential anthropogenic and natural factors influencing monk seal foraging success.

Foraging ecology studies of Hawaiian monk seals involve three primary areas of research: foraging habitat, diet, and characterizing and assessing prey abundance, which are conducted in collaboration with other programs at HL to address conservation issues that may be influenced by natural (e.g., El Niño) or anthropogenic (e.g., fisheries) events.

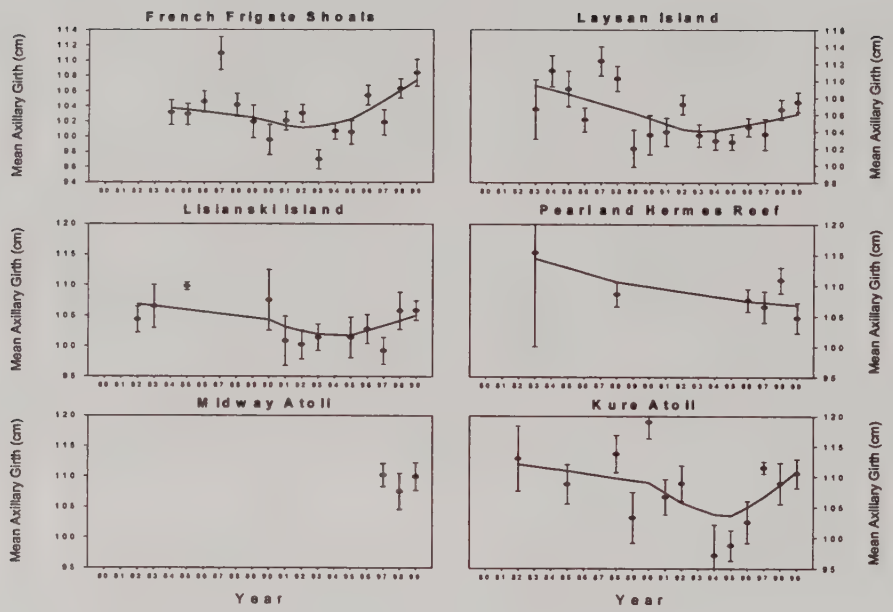

Figure 74. Trends in axillary girth of Hawaiian monk seal pups measured within 2 weeks of weaning at the six main reproductive subpopulations.

Foraging Habitat

Recent technological advances have made it possible to deploy instruments on monks seals and to obtain valuable new information on the foraging habitat of this endangered species. Recent studies using video camera (CRITTERCAM) deployments on adult male monk seals have documented benthic and deferral foraging on the deep slopes (60-100 m) of the atoll at FFS and neighboring banks. Seals fed on communities of cryptic fauna (fish and large invertebrates in transition "ecotone" regions of low relief where consolidated substracter, rubble, and talus bordered areas of sand. Independent areal surveys of bottom types using remote video cameras (n = 300 deployments) suggest that monk seals utilize a relatively small

percentage of the available benthic habitat (Fig. 75).

Recent deployments (1996-98) of miniature satellite tags have been used to investigate the foraging range of monk seals at two of the six main subpopulation locations, FFS and PHR. Results from this work support the food limitation hypothesis for the declining subpopulation at FFS, as conspicuous differences in foraging ranges of seals from FFS and PHR were found. Seals from FFS foraged over a much greater area than the seals from PHR (Fig. 76), perhaps due to lower prey availability. Similar data are not available from the remaining subpopulation sites, and no information exists on the foraging habits of weaned pups, which are likely most vulnerable to food limitation. Further information on monitoring monk seal forage base is found in the Coral Reefs and Marine Debris section.

In 1998, the Hawaii Undersea Research Laboratory (HURL) provided its submersible *Pisces V* to survey habitats utilized by monk seals and found beds of commercially valuable precious coral at these locations. These and other collected data led to a hypothesis that foraging monk seals visited deepwater coral beds. Monk seals may exploit aggregations of deepwater fish at the beds to improve their success at capturing prey. The relationship between foraging seals and deepwater corals is described in more detail under the Essential Fish Habitat and Precious Corals Fishery section.

Diet

Studies have been conducted to identify monk seal prey consumption based on scat (fecal) analysis (Fig. 77). The results have provided some insight to monk seal foraging, but specific conclusions have been limited due to biases inherent in the technique. The identification of prey from feces can be used as an index of prey consumption. However, scat analysis does not reflect the relative composition of prey in the diet because of variability in the digestion rates of different food items and in the distance between foraging locations and haulout sites where scats are collected. Such descriptive studies provide insight to general trends in prey consumption and likely reflect dramatic changes in productivity. CRITTERCAM studies have also provided valuable information on the diet and estimated size of prey consumed by free swimming monk seals (Table 10). The use of a new technique involving the matching of fatty acid signatures of monk seals (blubber samples) and their potential prey has shown promise and will likely provide valuable information on the relative importance of various prey in the monk seal diet. These results will be especially useful when attempting to assess potential competition for prey species (e.g., lobster) between commercial fisheries and monk seals.

Prey Abundance

Relative changes in abundance of reef fish at fixed stations have been surveyed annually at FFS and MID since 1995. Changes in herbivorous and carnivorous fish abundance are monitored and used to tracking potential changes in the abundance of monk seal prey. Monitoring included fish numbers, biomass, and size composition (see Coral Reefs and Marine Debris section). Studies have also been initiated to identify potential linkages between environmental change, oceanographic productivity, and monk seal prey abundance (see Coral Reefs and Marine Debris section). In 1998 surveys at FFS were extended to deeper slopes (60 m) to include fish communities in habitat where monks seals are known to forage.

Future Research Related to Foraging Ecology

Future work will involve continued characterization and assessment of monk seal habitat use, diet, and prey abundance. This research is vital for identifying and evaluating future recovery efforts and will focus on issues stemming from concerns associated with possible interactions between commercial fisheries and Hawaiian monk seals. Habitat use will be characterized through the use of time-depth recorders, CRITTERCAMS,

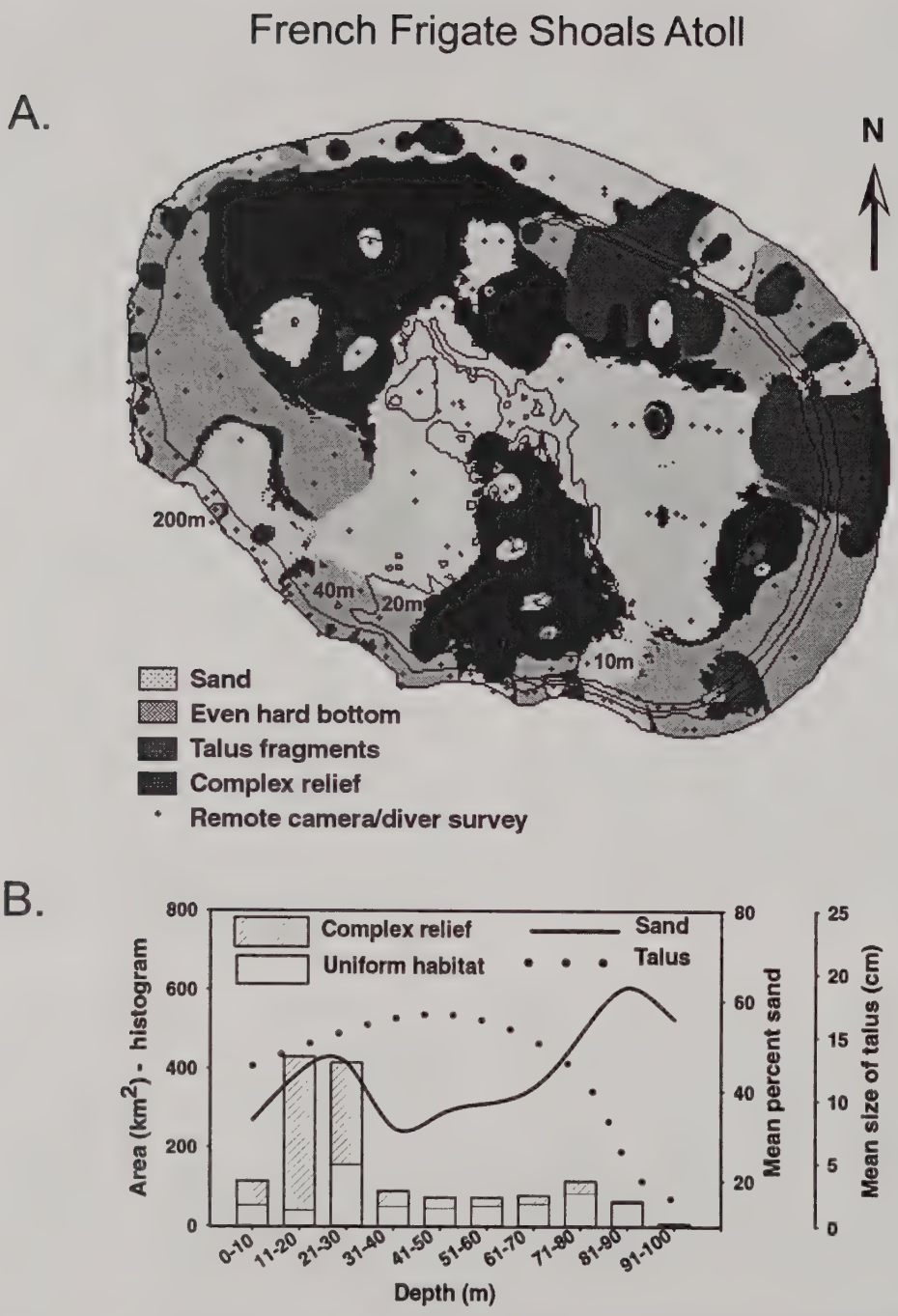

Figure 75. A. Generalized distribution of habitat surveyed at French Frigate Shoals. B. Graphical representation of French Frigate Shoals habitat by depth. Peak foraging contours (>60 m) compromise uniform habitat in transition from supporting largest fragments of erosional debris to predominant coverage by accumulated sand.

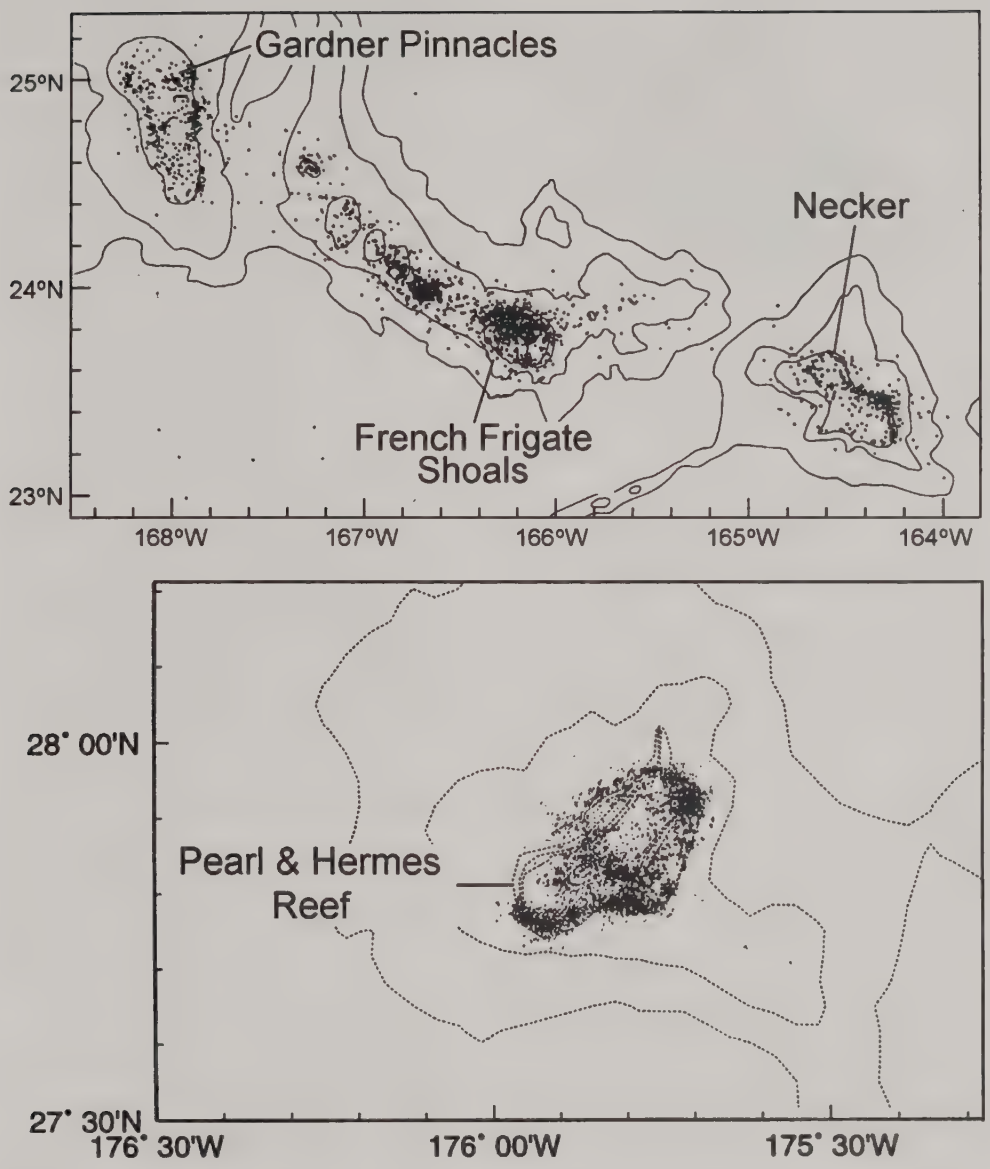

Figure 76. Satellite telemetry locations of Hawaiian monk seals instrumented at French Frigate Shoals and Pearl and Hermes Reef.

and satellite and radio telemetry. Prey consumption will be assessed through scat/regurgitate analysis, and the use of fatty acid signature analysis will be fully explored to assess the relative importance of lobster and other prey in the monk seals' diet. Prey abundance will be monitored during ongoing

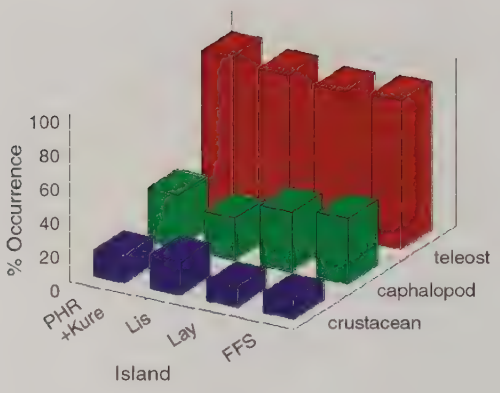

Figure 77. Percent frequency of occurrence of major prey groups in the diet of Hawaiian monk seals by location (from G. Lowe)

reef fish surveys, and the results will be examined for potential relationships to environmental changes in the marine ecosystem.

Health and Disease Assessments

The influence of disease on monk seal population trends is poorly understood. Disease processes may be important determinants of population trends through chronic low levels of mortality, or through episodic die-offs. The mass mortality of monk seals that occurred at LAY in 1978 may have been due to a disease process. Similarly, disease may be contributing to the high mortality of juveniles at FFS. In addition, the potential for disease transmission has been an important concern in management activities involving translocation of seals between reproductive sites. Disease may have contributed to the high mortality of seals translocated to MID during 1992-93.

Since 1997, a total of 125 serum samples from monk seals have been tested to evaluate exposure to viral and bacterial pathogens in three wild monk seal subpopulations (64 at FFS, 51 at PHR, and 10 at MID). Screening sera for exposure to numerous potential bacterial and viral pathogens has provided no compelling evidence to suggest that infectious disease(s) significantly influences population growth at these locations.

A companion study involving a comprehensive assessment of the health status of the Hawaiian monk seal was undertaken to

Table 10. Prey items eaten by free swimming seals as identified from videotapes recorded by CRITTERCAM.

Subfamily	Number seen	Estimated size
Anthiinae	2	9 cm
Balistidae	1	17 cm
Bothidae	1	12 cm
Cheilinninae	2	20 cm
Congridae	1	35 cm
Pentacerotidae	1	25 cm
Pomacentridae	1	7 cm
Tetradontidae	1	7 cm
Unidentified eels	2	25-35 cm
Unidentified fish	8	7 cm
Octopus	2	30+ cm

assess hematologic and biochemical parameters in this endangered species group and to establish normal baseline values for these parameters within age and gender groups of the species. Information from this study was used to compare the declining population at FFS and the increasing population at PHR. Standard laboratory techniques were used to measure each parameter for comparisons of adults between FFS (n = 34) and PHR (n = 29). FFS females had higher mean white blood cell counts than PHR females ($p<0.05$). The mean white blood cell counts were similar among males; however, significant increases in percent neutrophils and declines in percent lymphocytes and eosinophil were found for FFS males. Albumin, creatinine, and Na/K ratio averages were significantly higher among both females and males on FFS ($p<0.05$). The implications of these findings are uncertain but suggest that a subclinical disease process may be affecting monk seals on FFS, requiring further study.

An Hawaiian Monk Seal Epidemiology Planning Workshop is planned for September 11-12, 2000. In addition to a general evaluation of the implementation of the *Epidemiology Plan*, four specific research projects will be considered at the workshop. These projects will make extensive use of data which have already been collected, resulting in cost-effective applications of previously conducted field work. The projects are briefly described below and are designed to answer important questions regarding health and survival of monk seals.

Project 1 will assess the predictive value of recently collected (1999 field season) health data including morphometry, hematology and serum chemistry, parasite burden, and antibody responses to infectious agents on the survival of juvenile monk seals at FFS. This work will complement the pup survival study that was conducted on FFS during the 1999 and 2000 field seasons. Approximately one-half of all pups born at FFS in 1999 received a health assessment workup as outlined in the *Epidemiology Plan*. This project has the potential of providing important information on predictive risk factors for juvenile survival, a key to species preservation. Some of the potential risk factors are subject to mitigation through intervention. Therefore, if these factors are shown to be important predictors of survival, implementation of management strategies to assist juvenile pups through a transition period may become more critical. Further, if trends suggesting predictive value for health parameters are found, this will provide a cogent rationale to study additional cohorts of monk seals at FFS or other islands with similar techniques for potential interventions.

Project 2 will assess the effects of *Contracaecum* and *Diphyllobothrium* spp. parasitism on growth, body condition, and other health parameters among juvenile, subadult, and adult Hawaiian monk seals. This work will make use of previously collected data (1998 and 1999) on parasite burden and health parameters collected under the *Epidemiology Plan*. The existing data base will be used to provide insight into the potential relationship between qualitative (infected/uninfected) or quantitative parasite burdens (ova count) and growth, body condition, or other indicators of health. If a relationship is demonstrated, intervention to control parasite burdens may be warranted. These analyses may also identify specific parasites against which an antihelminthic program could be targeted, improving the specificity of a treatment regimen, prior to initiating any field studies or clinical trials.

Project 3 involves a comparison of various health parameters among juvenile, subadult, and adult monk seals at MID, PHR, and FFS. This work will extend the previous analysis research and include information collected throughout the 1999 field season. Previous analyses of adult monk seals at FFS and PHR identified several differences in health parameters that may be of clinical significance. These need to be confirmed to assure that the differences are not seasonal effects. In addition, these techniques have not been applied to juvenile or subadult monk seals to date. Further characterization of health endpoints may be indicated if the additional analyses confirm differences among monk seals at FFS, MID, and PHR.

Project 4 involves the assessment of the

potential role of body burdens of contaminants as determinants of various health parameters. To date, the work involving contaminants in monk seals has been preliminary and has involved collaboration with the U.S. Fish and Wildlife Service and the University of Hawaii. Several databases for contaminants in monk seals now exist, and some of these data can be linked to data on health parameters from the same animals. The role of anthropogenic contaminants on marine mammal health in general, and monk seals specifically, remains a matter of much conjecture. This work is especially important since there appear to be differences in the concentrations of contaminants between subpopulations that may impact reproductive success or other health parameters.

Finally, protocols for necropsy, specimen collection, serum banking, chemical restraint, and hematology have been developed and are being updated annually. A detailed reference collection is being compiled on health and disease of Hawaiian monk seals and other marine mammals. All previously collected biological specimens (i.e., serum, tissue samples from necropsies, etc.), and reports (i.e., examination forms, necropsy reports, etc.) are being catalogued and stored in a central location. Previously collected data on hematology, serum biochemistry, and other sample analyses are being incorporated into a comprehensive relational data base as they are collected. All seals that are handled for other studies routinely receive health/-disease assessments. This effort is designed to improve our understanding of health and disease in wild monk seals, and thereby better enable enhancement of the species' recovery.

Mitigation of Impacts to Enhance Survival

Translocation and Head Start Project

Since1981, captive care and release programs have been an important part of MMRP's efforts to salvage the reproductive potential lost at locations such as FFS where juvenile mortality is high. These projects have involved weaned female pups with a low probability of survival that were either kept on site for care/protection and released, (Head Start), or those rehabilitated at a captive facility on Oahu, Hawaii and translocated to more favorable reproductive sites. Recent growth in the population at KUR has resulted from the success of these efforts. The rehabilitation and release program reached a hiatus in 1995 when 10 of 12 captive females contracted an eye condition of unknown origin which made them unfit for release into the wild. In the future, variations of the previous translocation or Head Start projects will be considered to enhance the survival of weaned female pups.

Male Aggression

Mortality and injuries associated with male aggression are placed in two categories--multiple male aggression or "mobbing" and single male aggression. In 1994, 22 males were removed from LAY to balance the sex ratio. This successfully reduced the frequency of male-related injuries and deaths to adult females and juveniles of both sexes. In 1991 an aggressive male was euthanized at FFS, and in 1998 two aggressive males were relocated from FFS to Johnston Atoll as part of a successful effort to mitigate the male-caused mortalities of weaned pups. None of the translocated males have returned to their original locations, and the occurrence of injuries and deaths of females and immature monks seals has significantly decreased in all instances. Male aggression is carefully monitored at all sites annually to assess the efficacy of our actions and determine if additional mitigation is required.

Shark Predation

Recent studies have shown that shark predation has become a significant factor contributing to pup mortality at FFS. Pup deaths or disappearances related to shark predation have been either directly observed or inferred from known circumstances of shark predation on pups. Pup mortality or injury from sharks may occur weeks before weaning, unlike mortality related to male

aggression which usually occurs at or near weaning. Annual shark known and inferred mortality of pups < 4 weeks of age has been increasing since the mid 1990s (Fig 78). In 1999, shark predation accounted for the deaths of 51.1% (23 of 45) of the pups born at Trig Island (FFS) and 9.4% (25 of 244) of all pups born in the NWHI.

In 1998, at least 14 individual Galapagos sharks were tagged and observed hunting pups at Trig Island. At least 1-4 of the known sharks patrolled here daily and at least 8 of the 14 tagged sharks were resighted at least once during the same year (four Galapagos sharks were resighted at least 3 times). A systematic tag resight study of sharks was not conducted in 1999, but one of the tagged sharks from the 1998 study was associated with the killing of a pup.

During the 2000 field season, a study was initiated to assess the efficacy of a systematic removal of up to 15 sharks observed hunting monk seals at Trig Island and to eliminate or reduce predation on nursing pups in order to enhance early survival rates. This work will be conducted in conjunction with other concurrent studies which will determine the occurrence and number of sharks preying on monk seals and assess shark movement patterns within the atoll.

Removal of Marine Debris From Monk Seals' Haulout Areas

Despite international law prohibiting the intentional discard of plastics from ships at sea, the amount of debris washing ashore and entangling Hawaiian monk seals in the NWHI is high and has shown no sign of diminishing (Fig. 79). Most of the debris documented (i.e., nets and lines) was clearly from fishing or other maritime industries. Vessels may be continuing to dump debris despite regulations, or they may be losing gear during operations.

Hawaiian monk seals continue to be victims of marine debris (Fig. 80). During the seals' breeding season, MMRP biologists regularly monitor the beaches on which the seals haul out, removing any debris which could entangle the animals as part of an

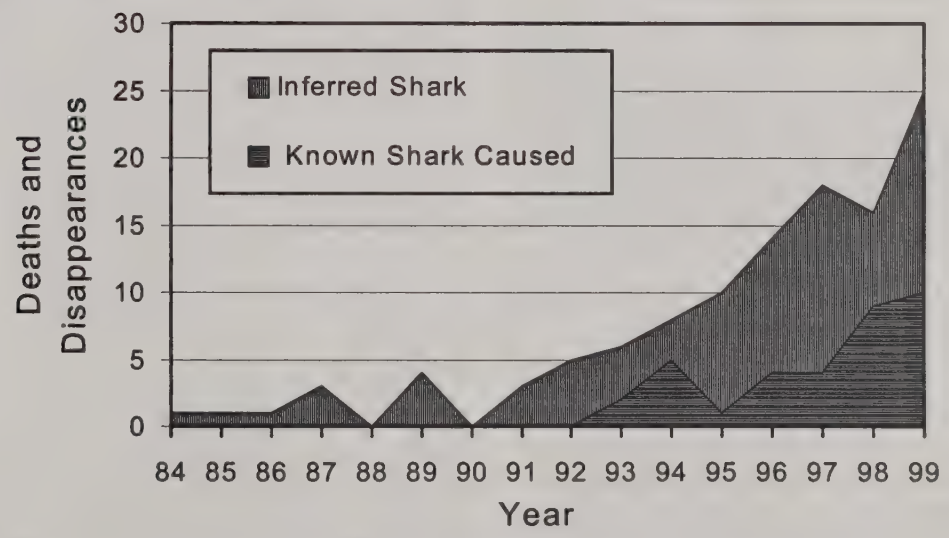

Figure 78. Trend in number of known and inferred shark-caused deaths of Hawaiian monk seal pups at French Frigate Shoals.

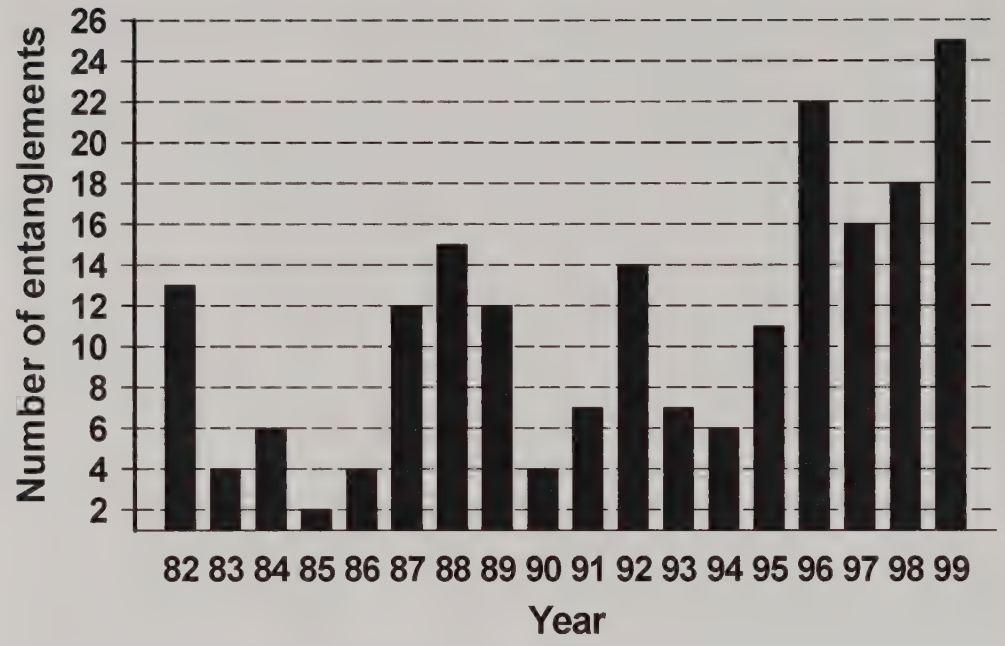

Figure 79. Number of Hawaiian monk seal entanglements observed, 1982-1999.

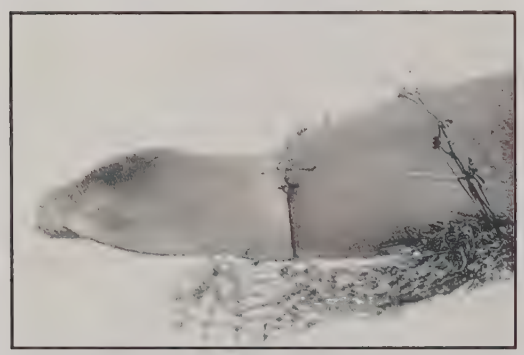

Figure 80. Hawaiian monk seal entangled in a fragment of fishing net.

ongoing project. Twenty-five Hawaiian monk seals are known to have become entangled in marine debris during 1999. This is the highest annual total ever documented by MMRP and is greater than both the 17-year (1982-98) annual average of 10.2 seals and the previous 5-year (1994-98) average of 14.6 seals. Nineteen of these animals were disentangled and released by MMRP field personnel, and 6 escaped unaided. Most (23) of the seals were encountered and released prior to sustaining debris lacerations (seals are also stressed due to the energetic burden caused by the extra weight and drag from the debris). Entangling items comprised lines (8), nets (6), net/line combinations (3), and other/unknown items (8) including cones from hagfish traps and plastic strapping bands. Four entanglements were observed on nearshore reefs, 20 were first observed when seals were on beaches, and 1 occurred at an unknown location (the seal was observed with an entanglement scar only).

In 1999, 2,774 pieces of potentially entangling debris were removed by MMRP personnel and cooperators from beaches at the six Hawaiian monk seal breeding sites, This is slightly fewer than the 3,136 pieces collected from the same sites in 1998. Marine debris was also removed from coral reefs to reduce the threat of entanglement to monk seals and restore the habitat (see Coral Reefs and Marine Debris section).

Human Disturbance

Disturbance of monk seals resulting from human activities in the NWHI (e.g., military activities, Coast Guard facilities) likely had a significant effect on monk seal population growth during the mid-1900s. The most conspicuous consequence of disturbance is the premature separation of suckling pups from their mothers which decreases the pup's chances of survival because of reduced fat reserves obtained from its mother's milk. Early separation of mother/pup pairs also increases the pup's vulnerability to shark predation and male aggression.

Since 1981, MMRP personnel have worked in collaboration with the USFWS, USN, and USCG to eliminate disturbance to monk seals on their haul-out sites. Human activity on beaches used by monk seals was significantly reduced after closure of USCG facilities at FFS (1979) and KUR (1992) and the USN facility on MID (1997). Subsequent to these closures, conspicuous increases were reported at all three population locations.

There is some concern that ecotourism conducted by a contractor to the USFWS on MID could result in deleterious human disturbance to monk seals. However, collaborative attempts between HL and USFWS have apparently been effective in keeping disturbances to a minimum.

MMRP continues to work with other government and nongovernment entities to build a stronger stewardship ethic to enhance the conservation and recovery of endangered Hawaiian monk seals.

Simulation Model to Evaluate Management Strategies

One objective of the Hawaiian Monk Seal Population Assessment Program is to improve the information available to guide management decisions. For example, management interventions in the monk seal population has involved rehabilitating and translocating female pups, removing adult males to reduce mortality from both single and multiple (mobbing) male aggression and, currently, mitigating Galapagos shark predation. The short- and long-term implications of such activities are usually not immediately apparent. Recognizing that a tool is needed to aid in decision making, HL has undertaken the development of a stochastic simulation model to realistically represent salient aspects of monk seal biology and allow managers to explore the likely outcomes of alternative management scenarios over various time horizons.

The monk seal simulation model requires a large number of parameters and initialization data, which are derived primarily from the annual population assessment research efforts. Information incorporated into the model include age/sex composition, survival and migration rates for each of the six subpopulations, and birth rates derived from two sites. The monk seal simulation model predicts future abundance and population structure for a monk seal meta-population consisting of six subpopulations. The model is spatially implicit with distinct demographic parameters for each subpopulation.

Routines in the model allow for the exploration of various management strategies given alternative scenarios. Translocation of female pups between sites and the effects of mortality from shark predation and both single and multiple male aggression can be assessed. Also, the likely outcome of mitigation of these sources of mortality can be explored. Though the model is user friendly for nonprogrammers, it is also complex and highly flexible. All demographic parameters can be altered, migration rates and density dependence allowed or not, and all probabilities relating to male aggression and shark predation can be set by the user. The monk seal simulation model is already a powerful tool for management decision making, and further improvements are ongoing.

Fisheries Interactions

The level of interaction between commercial fisheries and monk seals remains poorly understood. These interactions could include direct interaction with active gear of various fisheries (lobster trapping, bottomfish handline, pelagic longline, and potential interac-

tions with submersibles harvesting precious corals) as well as indirect interactions through reduced prey availability of the target species or bycatch. Concern over the potential for fishery interactions helped to promote designation of critical habitat for the monk seal in 1986. Also, lobster fishing was prohibited in waters less than 10 fm around all NWHI. In 1988, Maro Reef and waters around major haulout sites out to 20 fm were added to existing critical habitat. In 1991, additional protection of monk seal habitat was provided by the establishment of a Protected Species Zone, which prohibited longline fishing within 50 nmi around the NWHI and corridors between islands (Fig. 81).

Potential interaction between the commercial lobster fishery and monk seals is of concern, and the degree of possible competition between the two is being evaluated by assessing the relative composition of lobster in the diet of monk seals through the analysis of fatty acid signatures. This work involves the use of highly sophisticated models which analyze and match fatty acid signatures obtained from potential monk seal prey and from blubber samples of monk seals to determine the composition of prey in the monk seal diet. Results thus far are inconclusive and will require substantially more research.

Interactions between precious coral fisheries and monk seals potentially may occur if the removal of coral compromises essential fish habitat of associated fish prey that are consumed by monk seals. See the Essential Fish Habitat section for more information on the relationship between monk seals and precious corals.

Public Outreach and Education

An essential component to any wildlife conservation effort is the implementation of a public outreach and education program. MMRP is dedicated to the dissemination of information that will keep stakeholders informed and will build a stronger conservation and stewardship ethic. MMRP personnel are actively involved in lectures and seminars, oversight of the Monk Seal Watch Program, preparation of educational handouts and posters, and development of an informational website. They also collaborate with USFWS in an ecotourism effort at MID to educate visitors on site.

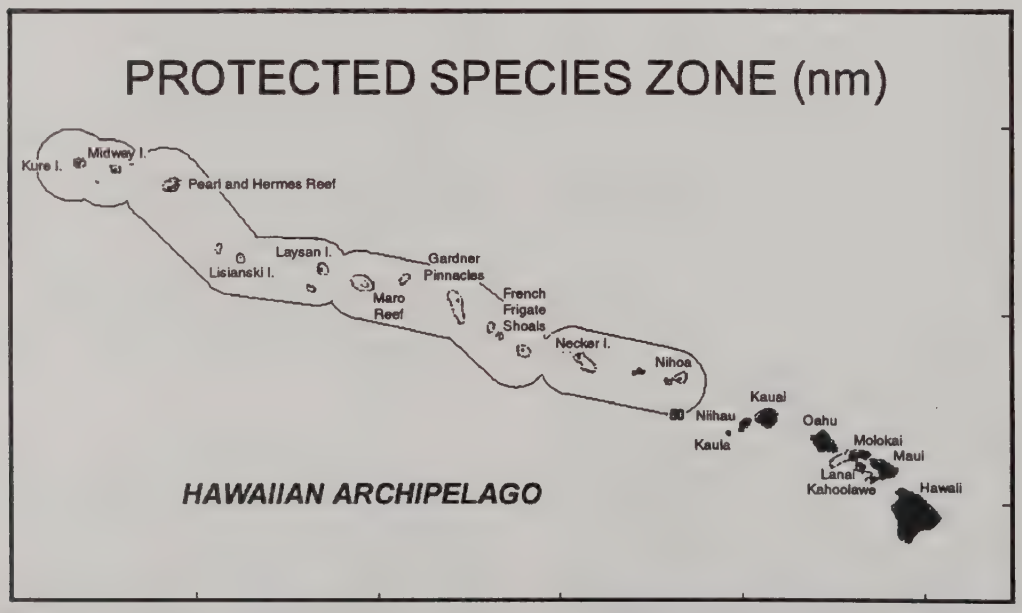

Figure 81. Northwestern Hawaiian Islands, showing 50 nmi Protected Species Zone in which longline fishing is prohibited.

PACIFIC SEA TURTLE RESEARCH AND RECOVERY

Background Information

Sea turtles are designated worldwide as threatened and endangered species. Population declines have been prominent in the Pacific Islands as the result of nesting habitat loss and excessive and widespread harvesting for commercial and subsistence purposes. The SWFSC Honolulu Laboratory (HL) is centrally located in the Pacific basin (Fig. 82), serving as a vital resource of sea turtle research expertise and assistance for areas from extending from Southeast Asia to the coasts of Mexico and Costa Rica. The principal species of concern to Pacific islanders are the green turtle, *Chelonia mydas* (Fig. 83), and the hawksbill, *Eretmochelys imbricata* (Fig. 84). Both species are the focus of considerable conservation efforts by the Regional Marine Turtle Conservation Program (RMTCP) of the South Pacific Regional Environment Programme (SPREP) based in Apia, Western Samoa. The SPREP is a nongovernmental organization providing assistance to the environmental needs of 22 Pacific Island nations. The HL plays an important role in assisting the SPREP in the conduction of the RMTCP. Presently native inhabitants of many Pacific Islands strongly desire to reverse declining trends of sea turtles so as not to lose an acknowledged important part of their cultural and nutritional way of life. This task will not be easy because of inherent biological constraints of most sea turtles, which include extensive oceanic migrations for reproduction, vulnerability to predation, unknown pelagic life stages, and slow growth resulting in delayed sexual maturity of 25 years or more.

Goals of the Marine Turtle Research Program

The goals of the Marine Turtle Research

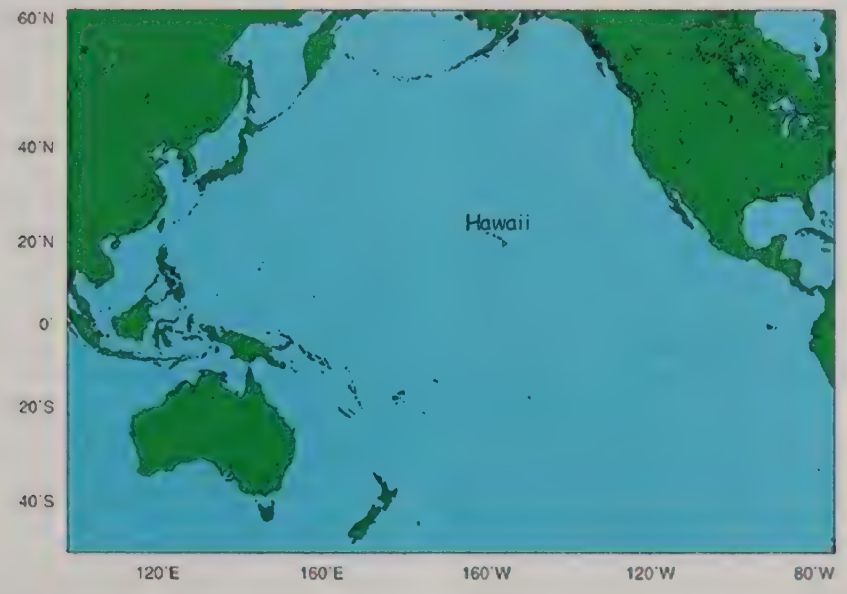

Figure 82. Map of Pacific Basin showing the area of SWFSC involvement in marine turtle research and conservation.

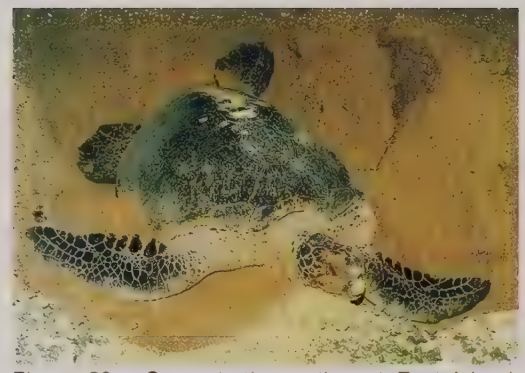

Figure 83. Green turtle nesting at East Island, French Frigate Shoals in the Northwestern Hawaiian Islands.

Figure 84. Hawksbill nesting in Samoa. This species is rare and endangered in most Pacific islands, but has recently shown a modest increase in Hawaii.

Program (MTRP) at HL are to achieve the biological recovery and sound long-term management of sea turtle populations in Hawaii and other U.S.-affiliated Islands in the Pacific Ocean, and to assist Pacific Island and Pacific Rim Nations in recovering sea turtle populations to the degree possible. To obtain the best scientific information possible to achieve this goal, research efforts at HL emphasize the following:

- Monitoring, assessment, and biological investigations at selected sea turtle breeding sites where nesting takes place, and at selected sea turtle foraging areas in benthic habitats of coastal waters.

- Investigating the pathology, etiology, and epidemiology of fibropapilloma tumor disease to formulate strategies for containment, cure, and prevention.

- Developing comprehensive computer simulation models and other quantitative tools to monitor population trends in order to better facilitate sea turtle recovery efforts and to assess impacts of fishery bycatch.

- Assessing post-hooking survival, movements and ecology in pelagic habitats, and mitigation relating to bycatch of sea turtles in longline fishing.

- Conducting cooperative research, technical assistance, and research training with Pacific Island and Rim Nations to promote the collection, analysis, and sharing of sea turtle data, including fishery bycatch data.

Sea Turtle Species

Five species of sea turtles are found in the Pacific Island and Rim Nations. Included are the green turtle, hawksbill, olive ridley (*Lepidochelys olivacea*), loggerhead (*Caretta caretta*), and leatherback (*Dermochelys coriacea*).

Green turtles, hawksbills, and olive ridleys–Green turtles in the Hawaiian Islands are genetically discrete and geographically isolated, unlike many of the other populations of turtle species in the region. Under the protection of the U.S. Endangered Species Act, the Hawaiian green turtle population has responded favorably to 22 years of recovery and research efforts by HL working in cooperation with the U.S. Fish and Wildlife Service (USFWS), the State of Hawaii, and several private conservation organizations. The greater numbers of green turtles in waters around the main Hawaiian Islands (MHI) have resulted in more opportunities for tourists and local people to view turtles in the water, in the same manner that humpback whales are an ecotourism attraction. The successes thus far achieved in the biological recovery of the Hawaiian green turtle constitute a model example in research and management for the rest of the Pacific Islands where population declines continue to occur. The olive ridley

nesting in the east Pacific has also shown a significant population increase in recent years under protective management and research by Mexican authorities. In contrast, hawksbills throughout the region are a rare and endangered species whose sparse nesting patterns make them difficult to study and protect.

Loggerhead and Leatherback turtles–There are two populations of loggerheads in the Pacific, one originating in Australia where serious declines are occurring, and the other in southern Japan where numbers of nesting females are uncertain, but possibly stable at present. Leatherbacks (Fig. 85) inhabiting the Pacific mainly originate from nesting beaches in Mexico and Costa Rica where catastrophic declines have been documented, in Indonesia where their status is uncertain but possibly stable, and Malaysia where the nesting colony is nearly extinct, mainly from excessive egg harvests, despite

Figure 85. Leatherback turtle nesting in the Eastern Pacific where serious declines have been documented.

30 years of conservation measures. Both leatherbacks and loggerheads are the species of principal concern with regard to incidental take in pelagic longline and other commercial fisheries of the Pacific conducted mainly by Japan, Taiwan, Korea and, to a much lesser extent, the United States.

Significant Research Activities

Population Monitoring

The number of Hawaiian green turtles nesting has substantially increased at the index nesting site of East (Hikina) Island, French Frigate Shoals (FFS) in the Northwestern Hawaiian Islands (NWHI). The numbers were less than 100 in the early 1970s and increased to 200-500 in the last decade (Fig. 86). However, the total number of nesting females in the population is still well below historical levels seen in the late 1800s. The number of green turtles observed in waters around the MHI has also increased significantly. Turtles in these foraging pastures are mostly immature turtles and are the direct result of the increased nesting success. Continued annual systematic monitoring and tagging is essential to determine the number of nesters and their health status at FFS, as a reliable index of overall population recovery.

Life History, Biology, and Ecology

Important progress is being made in understanding the biology, ecology, and life history of green turtles through long-term, in-water monitoring at study sites throughout the Hawaiian Islands. This involves the systematic capture, health-screening, recording of morphometrics, and double tagging with internal passive integrated transponder (PIT) tags to permanently identify individuals and to quantify turtle aggregations at designated long-term coastal study sites (Fig. 87). Growth rates of immature turtles, diets, habitat characteristics and use, daily foraging patterns, and trends in the number of turtles are being determined. For example, an analysis of data collected on 171 green turtles recaptured one or more times (of 1,458 tagged) at Palaau, Molokai yielded a mean growth rate of 2.1 cm per year in carapace length. The use of high technology acoustic telemetry, and dive recorders is revealing that green turtles undergo exceedingly limited daily movements between underwater resting areas and sites where feeding occurs on selected marine vegetation.

One of the critical determinants of population recovery of green turtles is the growth rate. Currently, HL scientists are collaborating with an expert in sea turtle skeletochronology at the National Museum of Natural History (Smithsonian Institution) to develop a model of Hawaiian green turtle growth. In this research, the ages of specimens found stranded on Hawaii shores are estimated

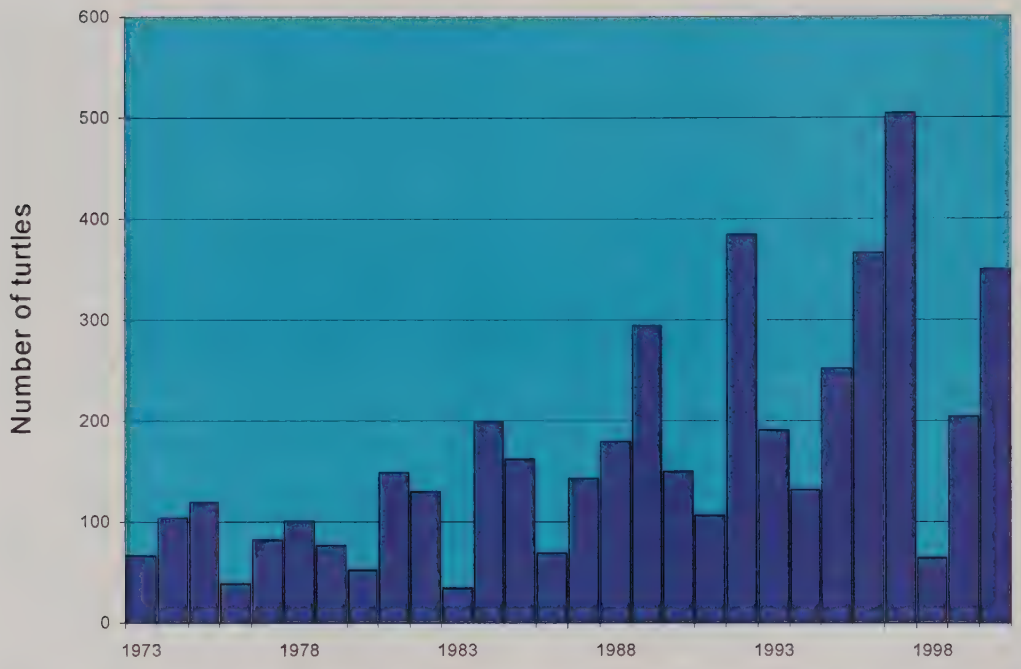

Figure 86. The number of green turtles nesting at the index study site of East Island has tripled since systematic monitoring started in the Hawaiian Islands in 1973.

from the pattern of growth increments on their humeri (flipper bones). Preliminary results indicate a close correspondence between growth rates estimated from the humerus analysis and those measured directly from tagged and recaptured turtles. The growth analysis is a critical step in building a simulation model of Hawaiian green turtle population dynamics that integrate information about the various life stages and processes.

Fibropapilloma Disease

Fibropapilloma Disease (FP) is a tumor-forming, debilitating, disfiguring, and often fatal disease of sea turtles, primarily green turtles, that has rapidly emerged in the past decade as a potentially serious threat to populations worldwide (Fig. 88). Significantly affected areas include Hawaii, Florida, certain sites in the Caribbean, and Australia. Olive ridley sea turtles on the Pacific coasts of Mexico and Costa Rica are also affected by FP. The disease is manifested by the formation of multiple fibrous masses of tissue 1 mm to 30 cm in diameter growing from the eyes, flippers, neck, tail, seams of scutes, and in the mouth. It is not uncommon for the tumors to also form in the internal organs. Although most FP tumors are histologically classified as "benign" (noncancerous), they can significantly disrupt and destroy the vital life functions of breathing, feeding, seeing, and swimming. The tumors also sometimes grow low-grade fibrosarcomas that destroy bony tissue. In advanced stages of the disease, turtles will often be lethargic, emaciated with soft and sunken plastrons, and prone to stranding ashore. Abnormal serum chemistry and hematology frequently are present. In addition, the pathology of FP is often associated with heavy burdens of internal parasites consisting of spirorchid cardiovascular flukes. FP has been shown to be transmissible in laboratory studies using injected cell-free tumor extracts.

Strandings of dead and live turtles offer an array of special research opportunities that are difficult or impossible to pursue by other avenues. In the Hawaiian Islands, a stranding and salvage research program started in 1982. This activity is carried out on six major

Figure 87. Local fishermen and their families provide valuable assistance in SWFSC studies of the life history, biology and ecology of sea turtles.

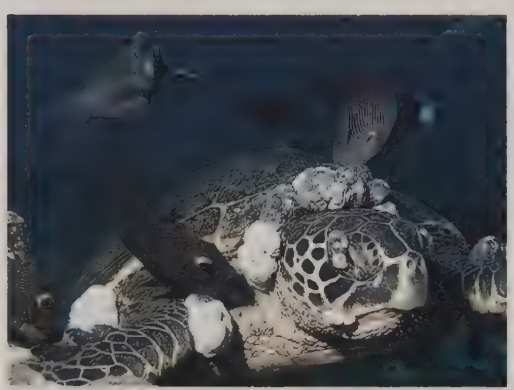

Figure 88. Green turtle with severe fibropapilloma tumors. Wrasses and surgeonfish sometimes pick at these growths thereby possibly transmitting the disease from one turtle to another.

inhabited Hawaiian Islands, in partnership with the State of Hawaii's Division of Land and Natural Resources (DLNR), the NOAA Sanctuary on Maui, the University of Hawaii's Joint Institute for Marine and Atmospheric Research (UH-JIMAR), Marine Options Program (MOP). Currently, the primary objective of the stranding research program is to obtain information relevant to the epidemiology of FP. The total number of strandings has increased annually over 18 years, from 10-20 cases in the early 1980s to 250-300 cases in the late 1990s. Most strandings are reported on Oahu. Strandings have decreased on Maui since a record high of 46 in 1996, but tumor prevalence here remains the highest of any island. Strandings occur evenly throughout all months of the year, and the monthly percent occurrence of tumored turtles is nearly constant.

The prevalence of FP has remained high in stranded turtles as well at long-term, in-water study sites of Kaneohe Bay, Oahu and Palaau, Molokai where live turtles are sampled periodically. Prevalence of FP in strandings has ranged from 39%-69% over the past decade with juveniles accounting for the highest frequency of tumors and for the majority of strandings (Fig. 89). In contrast, no cases of FP have as yet been encountered among the 700 turtles tagged and assessed along the 100-km western coastline of the Island of Hawaii. The severity of cases of FP, based on a progressive tumor scoring system of 0-3, has declined in Kaneohe Bay from 1989 to 1999. The growth rates of turtles with severe FP in Kaneohe Bay are significantly slower than moderately or unafflicted turtles (1.0 vs. 2.2 cm/yr in carapace length). The manifestation of mouth tumors with significant glottal (air passage) invasion is a unique and especially damaging aspect of FP in the Hawaiian Islands (Fig. 90). Mouth tumors and mouth and eye tumors in combination are highly prevalent in stranded turtles and their frequency has increased since 1990. Oral tumors are present in 17% and 31% of FP cases sampled alive in Kaneohe Bay and necropsied after stranding, respectively (Fig. 91). Internal tumors have increased in frequency since 1990. Up to 87% of FP turtles that are recaptured are juveniles and show an increase in severity; very few (4%-8%) in this size class exhibit tumor regression.

Polymerase Chain Reaction Amplification and other techniques have identified an alphaherpesvirus, a retrovirus, and possibly a

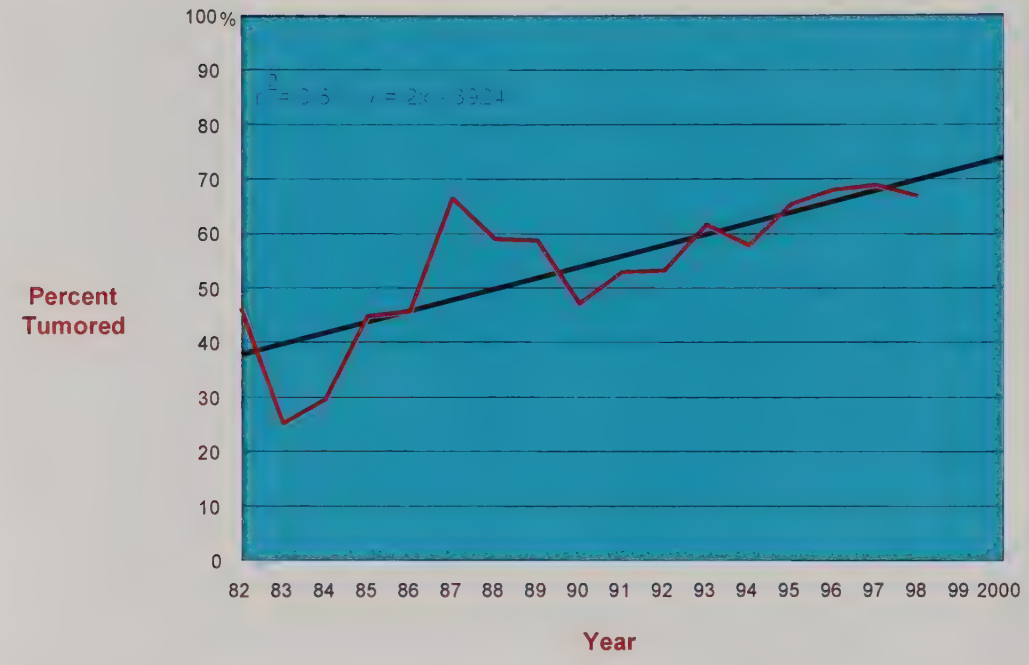

Figure 89. Percent tumored green turtles stranding in the Hawaiian Islands, 1982-99.

unique papillomavirus in FP-afflicted tissues as the result of collaborative research between HL and Cornell University, University of Florida, and UH Retrovirus Research Laboratory. Virus isolation efforts are in progress as a prerequisite for transmission studies to verify the disease-causing agent(s). Virus-free cell cultures using embryonic tissues of Hawaiian green turtles have been established for in vitro studies by the U.S. Geological Service's (USGS) National Wildlife Health Center (NWHC). Laboratory techniques have been developed in collaboration with the Honolulu Field Station of NWHC to measure the humoral (antibody) and cellular (cell mediated) immune responses of clinically healthy green turtles held in captivity at the Kewalo Research Facility (KRF). Research has recently been completed measuring the immunocompetence of turtles in the wild at Hawaii FP and non-FP habitat locations. The results of this comprehensive investigation, now submitted for journal publication, strongly suggest that immunosuppression is a result of FP rather than a prerequisite leading to the disease.

Preliminary analysis of green turtle tissues with FP has confirmed the presence of okadaic acid, a biotoxin shown to promote tumors in mice. Benthic dinoflagellates, *Prorocentrum* spp., which are known to produce okadaic acid, have been identified and quantified on algae and seagrass consumed by Hawaii's green turtles in a field study conducted by HL in collaboration with Dr. Jan Landsberg of the Florida Marine Research Institute. Nearshore coastal foraging habitats at high-risk for FP have a high prevalence and abundance of *Prorocentrum* spp. Whereas, non-FP foraging areas (the entire west coast of the Island of Hawaii) have very low *Prorocentrum* spp. HL is sponsoring a graduate student, and former University of Hawaii undergraduate now at the University of Florida, to expand the *Prorocentrum* research to include seasonal comparisons between selected habitats in both Hawaii and Florida.

UH has analyzed remote videotape of the cleaning relationships between Hawaiian reef fishes and green turtles to provide baseline data on the potential role of cleaner fishes

transmitting FP between turtles. Turtles with FP may also be deterred from visiting cleaning sites because of painful bites to tumors by fishes. Some tissues from cleaner fishes have been found to test positive by polymerase chain reaction (PCR) for herpesvirus.

Mexus Pacific FP and other collaborative research of eastern tropical Pacific Mexican sea turtles, mainly olive ridleys, has continued to be a highly successful cooperative study, involving information exchange and research training. This project is conducted with Dr. Javier Vasconcelos (Director) and staff of the Centro Mexicano de la Tortuga INP sea turtle research station in Oaxaca, Mexico. Collaborative investigation has been accomplished to assess histopathological characteristics and viral presence in tumors occurring in nesting olive ridley adults. This specialized disease and health assessment work is being conducted in part under contract by HL to veterinary researchers Drs. Alonso Aguirre and Terry Spraker. There is an exceedingly high level of cooperation and mutual professional respect among all parties involved in the international effort to study a disease problem shared by Hawaii and the Pacific coast of Mexico. Recently, a cooperative satellite tracking project of olive ridleys in Oaxaca was also initiated under the Mexus Pacific framework, at the request of Mexican scientists.

Turtle Population Dynamics and Impact Assessment Studies

Research to develop an understanding of sea turtle population dynamics is fundamental to effective management of human impacts and population recovery. HL has continued comprehensive research on modeling the population dynamics of Hawaiian green turtles. One essential piece of the green turtle population model is a model of age and growth, which has just been developed based on analysis of increments (periosteal layers) assumed to be formed annually on the turtles' flipper bones (humeri). Research will soon begin to estimate survival rates and other critical population parameters of Hawaiian green turtles based on accumulated tag-recapture data collected in nearshore surveys.

In addition to the population studies on Hawaiian green turtles, studies are continuing with the objective of assessing the status and dynamics of other sea turtle populations taken incidentally in the Hawaii longline fishery. Particular attention is being given to Pacific leatherbacks and Japanese loggerheads. In support of this, development continues with the TURTSIM turtle population simulator, a computer simulation modeling tool that integrates information about turtle life history and biology with information or assumptions about human-caused mortality to enable studies of human impact scenarios and turtle population recovery strategies. The objective of current TURTSIM studies is to develop models of individual turtle populations to the extent feasible. Guidance on population structure is provided by ongoing genetic studies of specimens captured in various fisheries and on nesting beaches (this work is conducted by Dr. Peter Dutton of Southwest Fisheries Science Center (SWFSC) La Jolla Laboratory in collaboration with other NMFS staff and cooperating scientists outside NMFS). Models developed with TURTSIM require the creation of databases of biological parameters and estimates of the full range of human-caused mortality. In both cases, data are often scarce or non-existent. Accordingly, provisional values of many critical biological parameters and levels of human-caused mortality must be based on best guesses.

Because most sea turtle populations inhabit the territorial waters of several countries, as well as the high seas, during their life cycle international cooperation is essential to the success of turtle population research and recovery efforts. Primary attention is currently being given to using TURTSIM to assess impacts of the Hawaii fishery and other human activities on the declining Mexican leatherback population in collaboration with the principal Mexican leatherback scientist, Laura Sarti. This study is being carried out as part of the MEXUS-Pacifico cooperation between the two countries. Similar collaborations are underway with the principal loggerhead scientist in Japan, with respect to loggerheads taken in the Hawaii fishery.

Satellite Tracking to Estimate Post-Hooking Survival

This research was initiated in June 1997 by HL working in partnership with the Southwest Region (SWR) Observer Management Program. The objective of this work is two-fold: to estimate post-hooking survival and to gain insight into the ecology and oceanic movements of turtles in distant pelagic habitats. To date, small satellite transmitters have been deployed from Hawaii-based commercial longliners on 38 hooked loggerheads, 11 olive ridleys, and 3 green turtles (Fig. 92). Twenty-seven of the deployments have resulted in pelagic trackings ranging from 0.2 to 8.2 months duration covering distances of 13-7,282 km. The remaining 13 deployments

Figure 92. Pelagic olive ridley fitted with a satellite tag aboard a commercial long line vessel north of the Hawaiian Islands.

have produced no tracking data, and all of these involved turtles that were classified as "deeply hooked" (hook lodged in the esophagus and impossible to remove). Of the 39 tracked turtles, 22 were deeply hooked and 17 "lightly hooked" (the hook was in the jaw or elsewhere externally allowing easy removal). There were no significant differences between these two groups for the duration of transmissions in months or the distance the turtles traveled. Additional analyses of these data are in progress that include the percent time spent diving and on the surface for use in estimating apparent normal and abnormal foraging behaviors in the two groups of turtles.

The results of satellite tracking research relevant to loggerhead pelagic foraging habitat, and a possible management strategy to separate longline fishing from high-sea, turtle-use zones was recently published. Discussions related to sea turtles are also found in other sections of this document–Interactions of Hawaii-based Longline Fishery and Fishery Oceanography.

Research Line Entanglement from Shoreline Fishing

Recently in Hawaii there has been an increasing prevalence, accompanied by public awareness, of sea turtles entangled with monofilament fishing line believed to be from recreational fishing. Most of the turtles are alive but with a severely strangulated and necrotic front flipper (Fig. 93). Treatment involves surgical amputation by a clinical veterinarian working with HL. This is followed by a period of captive care and rehabilitation at KRF. Returning such turtles to the wild, where they function reasonably well, has

Figure 93. Severely strangulated front flipper of a green turtle entangled with 6-lb. test monofilament fishing line.

been successfully carried out. However, prevention and mitigation of this problem is being pursued through the collection of basic research data on both turtle habitat use and recreational fishing patterns.

CORAL REEFS AND MARINE DEBRIS

CORAL REEF ECOSYSTEM RESEARCH AND PROTECTION

Background Information

Coral reefs are among the most diverse and biologically complex ecosystems on earth, harboring a richness of corals, reef invertebrates, fish, and other fauna and flora. Coral reefs and their associated habitats provide economic and environmental services to millions of people as areas of natural beauty and recreation, sources of food, jobs, chemicals, pharmaceuticals, and shoreline protection. In addition, reef habitats play a central cultural role among U.S. Pacific Islands, where community-based conservation, subsistence fisheries, and protected areas have been successfully managed for generations. Accounting for 94% of the nation's coral reefs, the U.S. Pacific Islands include 1) the State of Hawaii, which contains the highest proportion of endemic marine species of any island group in the world; 2) the Territories of Guam and American Samoa and the Commonwealth of the Northern Mariana Islands (CNMI), which are in the world's most biodiverse marine ecosystem, the Indo-Pacific; and 3) the remote islands and atolls of the central Equatorial Pacific (Howland, Baker, Jarvis, Johnston, Wake, Palmyra, and Kingman), which are among the nation's least damaged and least known coral reef ecosystems (Figs. 94 and 95).

Coral reef ecosystems around the globe are now threatened by an increasing array of overexploitation, pollution (including marine debris), habitat destruction, invasive species, disease, bleaching, and global climate change. The rapid decline of these diverse marine ecosystems has significant social, economic, and environmental impacts here in the U.S. Pacific Islands and around the world. In response to this growing global environmental threat, President Clinton issued the

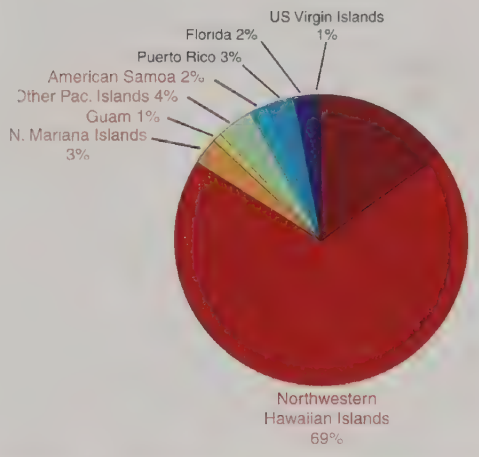

Figure 94. Percentage of U.S. coral reefs by area (Miller and Crosby, 1998)

Coral Reef Executive Order 13089 on June 11, 1998 to lead U.S. efforts, both domestically and internationally, to protect, restore, and sustainably use coral reef ecosystems. Chaired by the Secretaries of Commerce (NOAA) and Interior, the U.S. Coral Reef Task Force is composed of the heads of 11 Federal agencies and the governors of seven states, territories or commonwealths with responsibilities for coral reefs. In *The National Action Plan to Conserve Coral Reefs*, distributed in March 2000, the Task Force identified two fundamental themes for immediate and sustained national action:

- Understand coral reef ecosystems and the natural and anthropogenic processes that determine their health and viability.
- Reduce the adverse impacts of human activities on coral reefs and associated ecosystems.

Figure 95. U.S. Pacific Islands and associated economic zones (EEZs)

More specifically, the *Action Plan* calls for conducting comprehensive mapping, assessment, and monitoring of coral reef habitats; supporting strategic research on regional threats to coral reef health and the underlying ecological processes upon which they depend; and incorporating the human dimension into conservation and management strategies. To reduce the adverse impacts, the *Action Plan* calls for creating an expanded and strengthened network of federal, state and territorial coral reef marine protected areas (MPAs); reducing the adverse impacts of extractive uses (including fishing); reducing habitat destruction; reducing the impacts of international trade in coral reef species; improving governmental accountability and coordination; and creating an informed and engaged public for coral reef conservation. On May 26, 2000, the President reiterated the national commitment to these themes by issuing another Executive Order to 1) strengthen the management, protection, and conservation of existing MPAs and establish new or expanded MPAs; 2) develop a scientifically based, comprehensive national system of MPAs representing diverse marine ecosystems and the nation's natural and cultural resources; and 3) avoid causing harm to MPAs through Federally conducted, approved, or funded activities. In his announcement, the President specifically requested that the Commerce and Interior Departments work with the State of Hawaii and the Western Pacific Regional Fishery Management Council (WPRFMC) to expand and strengthen MPAs in the Northwestern Hawaiian Islands (NWHI).

Goals and Objectives

To address these national and regional concerns, Honolulu Laboratory (HL) has initiated a comprehensive multiagency program to assess, monitor, restore and protect coral reef ecosystems of the U.S. Pacific Islands. In cooperation with our multiagency partners, the goals of this program are to:

- Improve understanding of coral reef ecosystems of the U.S. Pacific Islands through assessment and long-term monitoring.

- Evaluate and reduce adverse impacts to coral reef ecosystems of the U.S. Pacific Islands, with particular emphasis on those related to fishing activities.

- Enhance coral reef fisheries management and conservation by assisting the WPRFMC develop and implement a Coral Reef Ecosystem FMP.

- Expand, strengthen, and establish scientifically based marine protected areas to conserve coral reef ecosystems of the U.S. Pacific Islands.

The specific objectives of this program are to:

- Conduct baseline assessments of the condition, health, and underlying biotic and abiotic processes of the coral reef ecosystem of the U.S. Pacific Islands.

- Establish a program to monitor the health of coral reef ecosystems and Essential Fish Habitat to enable managers to evaluate anthropogenic and natural changes in a timely manner.

- Develop a cost-effective mooring and remote-sensing capability to continue monitoring coral reefs and essential fish habitat of the U.S. Pacific Islands over the long term.

- Conduct mitigation efforts focused on removal of marine debris and other threats to coral reef ecosystems of the U.S. Pacific Islands.

- Establish a multifaceted coral reef damage prevention program consisting of source identification, monitoring, tracking, and at-sea removal of derelict fishing gear using international government and industry partnerships, remote sensing, and ocean circulation modeling; and enhanced public awareness and education efforts.

Major Research Activities

Assessment and Monitoring Program

Monitoring the Monk Seal Forage Base–Annual surveys of the shallow reef fish prey of endangered Hawaiian monk seals continued by HL in 1999 with surveys at French Frigate Shoals (FFS) and Midway Atoll (MID). These surveys extended the time series to five consecutive years (1995-99, inclusive) at each site, in addition to surveys conducted previously (in 1992 at FFS; in 1993 at MID). These surveys established a new baseline for comparison with an initial characterization provided by U.S. Fish and Wildlife Service (USFWS) surveys conducted during 1980-83. As on all previous annual surveys, trained diver-observers used consistent procedures to visually estimate the numbers and biomass of fishes encountered at the same series of four barrier reef and five lagoonal patch reef stations at each site. The study was designed, based on examination of the 1980-83 and 1992-93 data, to develop the ability to detect changes of 50% or greater in fish densities over a decade-long series of annual surveys.

A comprehensive evaluation of the potential changes detectable after completion of the 1999 surveys is the subject of a pending HL Administrative Report. Briefly summarized (Fig. 96), major temporal changes (and spatial similarities and differences between FFS and Midway Atoll (MID)) that have been detectable to date include 1) the occurrence of an apparently infrequent, but spatially broad year-class effect (young-of-the-year (YOY) recruitment spike in 1995) for many reef fish species at both FFS and MID; 2)

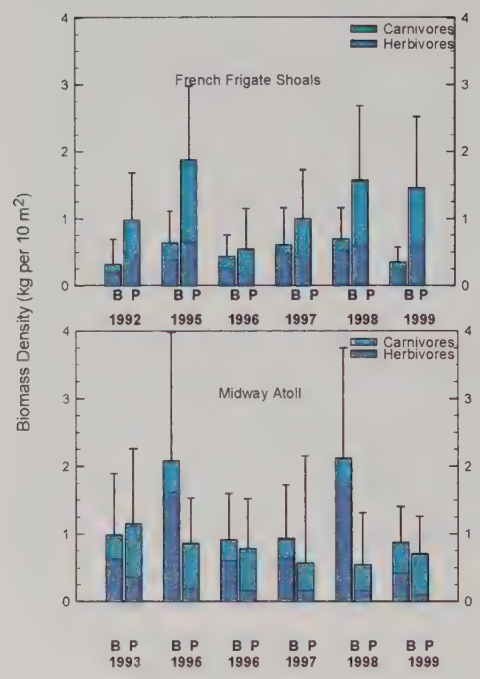

Figure 96. Estimates of biomass density of fishes encountered at the same series of four barrier reef and five lagoonal patch reef stations at French Frigate Shoals and Midway Atolls from annual diver surveys since 1993. Carnivores are shown as light blue and herbivores are shown as dark blue.

lower densities of two major monk seal prey items (moray eels: 13x lower; lizardfishes: 5x) at FFS, where monk seals are relatively abundant, compared to MID, where predatory seals are relatively scarce; and 3) a persistently low frequency occurrence of large carangids (jacks) at MID, where these predators had been fished by U.S. Navy (USN) personnel prior to transfer of MID to the USFWS in 1996, and where they have been the targets of a recreational catch-and-release fishery since that time. Perhaps the key observation thus far relevant to monk seal foraging ecology is that, for all lower trophic level taxa pooled, the standing biomass of fishes on shallow barrier and lagoonal patch reefs has averaged without pattern around 1 kg per 10 m^2 during most of the past decade at the two sites. This suggests that overall prey abundance is too coarse-grained an indicator of the resource base (even for this generalist predator) because prey availability is more relevant to monk seals than is prey abundance.

Another pair of annual surveys at these two sites is scheduled for the summer of 2000. Reef fish numbers and biomass will again be estimated in situ using historical methods at the same series of nine stations at each site. In addition, a methods calibration study is planned to bridge between the existing time series based on direct-diver counts and a new series of expanded NWHI reef surveys based on diver-held digital video records (Fig. 97).

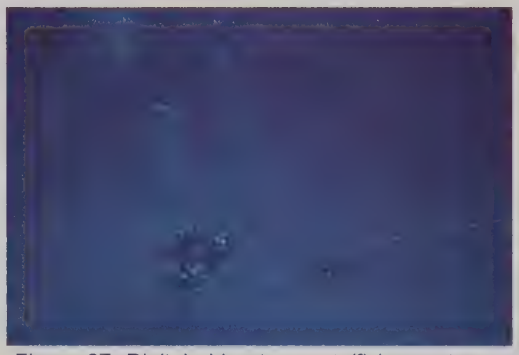

Figure 97. Digital video transects/fish counts were conducted using towed diving sleds.

Baseline Assessments–Baseline rapid environmental assessments (REAs) of the condition and health of some of the most remote and pristine coral reef ecosystems of the U.S.-affiliated Pacific Islands began in earnest in March 2000 with a cruise of the NOAA ship *Townsend Cromwell (TC)* to the U.S. Line and Phoenix Islands. A multidisciplinary team of coral, algae, and fisheries biologists and oceanographers from HL and USFWS conducted a series of 2-3 day REAs at Palmyra and Kingman Atolls and Howland, Baker, and Jarvis Islands (part of the Pacific Remote Islands National Wildlife Refuge

Complex administered by the USFWS) (Fig. 97). The REAs focused on obtaining high-quality digital video records of the fauna and habitat; describing relative abundances of species and higher taxa within major taxonomic groups (corals, fishes, benthic macro-invertebrates, algae, and protected marine mammals and turtles); developing spatial databases of resource and coral reef habitat distributions; and characterizing oceanographic conditions at the time of the observations.

During the cruise, researchers conducted towed diver digital video transects/fish counts on economically and ecologically important taxa covering 102.9 linear km; 70 stationary fish count survey dives; 22 roving diver fish survey dives; fifty 20 m^2 fish transects; and 30 coral, algae, macro-invertebrate survey dives. Five permanent long-term monitoring stations were established and surveys for corals, algae, macro-invertebrates, and fish were conducted at each. Oceanographers mapped the vertical structure of the water column surrounding each of the islands/atolls by conducting 107 conductivity-temperature-depth (CTD) casts and shipboard acoustic Doppler current profiler (ADCP) transects. Surveys of birds and vegetation were conducted, and P-coded Global Positioning System (GPS) shape files were produced at each of the five islands/atolls. The digital video data set from the towed and roving diver transects totals 65 hours (or 1,200 Gbytes of information). Over 1,000 still photographs were taken during the coral, algae, macro-invertebrate survey dives. All of the stations and transect locations were recorded with Global Positioning System (GPS) and entered into an ArcView Geographic Information System (GIS) (Fig. 98).

Reef ecosystems of these remote islands appear to be in generally good health. Evidence of past large-scale coral mortality events were apparent at some sites and were probably related to significant interannual or longer-term climate fluctuation, such as El Niño. Evidence of fishing pressure was observed, particularly at Palmyra and Kingman Atolls, where abundances of reef sharks and

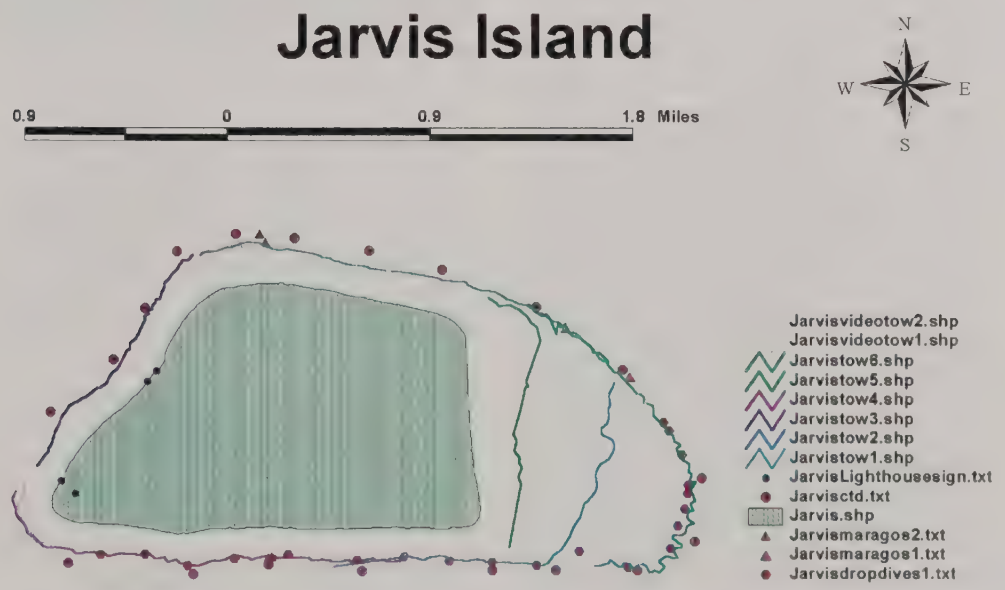

Figure 98. Geographic Information System (GIS) map showing locations of survey activities conducted during rapid ecological assessments at Jarvis Island

other large economically valuable fishes; e.g., jacks, groupers, and snappers, were low relative to other reefs surveyed. Marine debris surveys revealed only small amounts of derelict fishing gear, all appearing to be of local origin. Many resources which have been overexploited in other reef ecosystems around the world were found to be abundant. Based on these surveys, these remote areas may be prime candidates for consideration as MPAs as directed by the President's Executive Order.

A second cruise to the equatorial central Pacific is scheduled for January-February 2001 pending the availability of new funding. The major objective of this cruise is to further quantify fish and other important, e.g., *Tridacna* clam resource densities, and thereby complete a comprehensive baseline assessment. It is anticipated that based on results of the complete baseline assessment, future cruises will be conducted to monitor representative areal subsets for indicator taxa.

In September 2000, a baseline assessment of coral reef ecosystems of the NWHI will be conducted in partnership with the USFWS, the State of Hawaii, and the Hawaii Coral Reef Initiative-funded NOW-RAMP. Like the NMFS-USFWS equatorial cruise, the NWHI reef assessment cruises will utilize REAs to characterize the major biota and habitats. However, since the biota of the NWHI is comparatively well described, additional emphasis will be placed on quantifying resource abundances. Subsequent annual cruises (the first scheduled for September of 2001 pending the availability of new funding) will be used to monitor changes in target taxa and essential fish habitat within representative areas and oceanographic conditions generally.

In addition to the *in situ* assessment and monitoring activities, HL scientists are working with USFWS, the National Ocean Survey (NOS), and other agencies to acquire and utilize satellite and aerial hyperspectral and multispectral imagery to spatially map and greatly expand the more detailed in situ surveys. In March 2000, IKONOS panchromatic and multispectral satellite imagery of Howland, Baker, and Jarvis Islands was purchased by the USFWS to allow cooperated in agencies to examine the coral reef habitats (Fig. 99). HL-towed diver-digital video

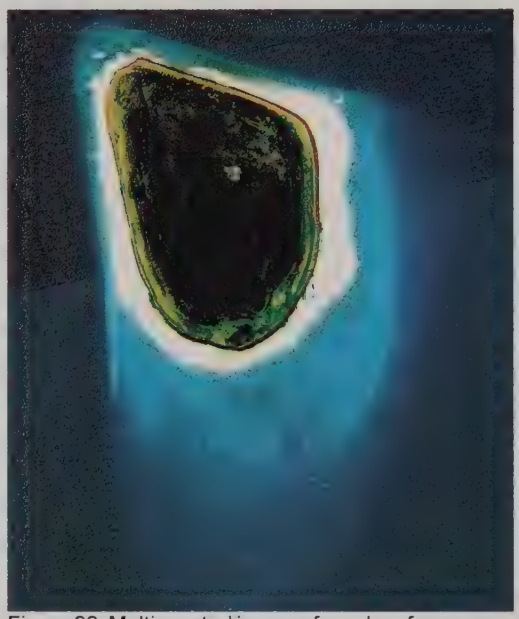

Figure 99. Multispectral image of coral reef resources at Baker's Island from IKONOS satellite. Pixel resolution is 4 m. Photo courtesy of USFWS.

records taken during the March 2000 assessment cruise will be used to ground-truth this imagery and provide habitat characterizations. HL oceanographers are monitoring oceanographic conditions at these sites using satellite remote sensing. They are also proposing a system of coral reef moorings and shore stations to monitor biotic and abiotic processes at remote sites and telemeter data and warnings in near real-time to the NOAA CoastWatch site at HL for distribution on the Worldwide Web (www) to scientists and resource managers.

Coral Reef Restoration Program

HL has established a Coral Reef Restoration Program to mitigate some of the known

and yet-to-be-determined sources of degradation to coral reefs of the U.S. Pacific Islands. Initial efforts are focusing on expanding the existing HL-led multiagency cooperative efforts to remove several thousand tons of marine debris from the coral reefs and beaches of the NWHI. These restoration efforts are discussed fully in the section focusing on Marine Debris.

Coral Reef Protection Program

Coral Reef Ecosystem Fishery Management Plan–Coral reef-related studies at HL are mandated by the Executive Orders on Coral Reef Protection and Marine Protected Areas and the need to provide scientific advice and guidance to the WPRFMC in developing and implementing an effective Coral Reef Ecosystem FMP. Research in support of the Coral Reef Ecosystem FMP hinges more specifically on evaluations of the resources and the effectiveness of no-take MPAs in particular reef ecosystems subject to different types of human impacts.

Research recommendations of the Coral Reef Ecosystem FMP would require multidisciplinary studies of reef ecosystems throughout both the NWHI and the other U.S. Pacific Islands. Major pending research topics include assessment and monitoring of fisheries-related reef resources, particularly as they relate to the identification and protection of areas as EFH, including Habitats of Particular Concern, and the siting and evaluation of the effectiveness of no-take MPAs. A complementary focus is modeling the short-term versus long-term costs and benefits, including socioeconomic, of these no-take MPAs.

MPAs–MPAs have been identified by the U.S. Coral Reef Task Force as one of the most important and effective management tools for conserving coral reef resources and biodiversity over the long term. In support of the Task Force's *Action Plan* and the President's Executive Order on MPAs, HL is working with partner agencies in NOAA, the Interior Department, the State of Hawaii, the Territories of Guam and American Samoa, the CNMI, and the WPRFMC to provide scientific advice necessary to identify, select, and establish MPAs which will conserve these important ecosystems, provide sustainable use of resources, and preserve the cultural heritage of many Pacific Islanders. HL, in conjunction with some other partners, will be conducting baseline assessments of the status of these ecosystems which will play a key role in identifying and selecting these sites based on the best available scientific information. HL's coral reef ecosystem monitoring program will provide the scientific information needed to evaluate the effectiveness of the MPAs in conserving and protecting the reef resources over the long term.

Coral Reef Education and Outreach

The final, and arguably most important, component of the HL coral reef ecosystem protection program is effective education and public outreach aimed at effectively communicating up-to-date scientifically based information on the status, conditions, potential threats, and values of these ecosystems to both resource management agencies and the general public. With a well-educated and informed public, including fishing and other extractive uses industries or potential industries (biotechnology), resource management agencies will be better supported in trying to determine the most effective conservation and protection strategies while taking into account potentially conflicting interests.

Some examples of HL's coral reef ecosystem education and outreach activities include production of two educational videos aimed at educating the public about the chronic threat of marine debris and active participation and leadership in co-hosting the upcoming International Marine Debris Conference.

MARINE DEBRIS

Background Information

The Northwestern Hawaiian Islands (NWHI) comprise 69% of the Nation's coral reefs. Surveys of the these Islands from 1979 to1983 reported relatively pristine reefs, but by 1996 the reefs were suffering from substantial anthropogenic damage, primarily due to the effects of derelict fishing gear. While land-based sources may be responsible for the majority of marine debris in the world's oceans, debris of a maritime origin may pose the greatest threat to ecosystem health in the NWHI. The remote central Pacific location and extensive shallow reefs of the NWHI filter derelict fishing gear originating throughout the Pacific Rim. The North Pacific Subtropical Convergence Zone provides a mechanism for debris accumulation in this region. Much of this accumulated debris is ultimately deposited on the coral reefs and beaches of the NWHI.

The movement of derelict fishing gear across shallow atolls threatens the ecological balance of the reef community. Once derelict fishing gear snags on the atolls of the NWHI, it begins a cycle of destructive activity. Derelict fishing gear modifies the reef structure itself by damaging the coral substrate that comprises the reef. After snagging on coral reefs, wave action acting on the debris breaks the coral heads on which debris is fixed, liberating the debris to subsequently snag and similarly damage additional coral. This action continues until the nets are removed, or become adequately weighted with abraded coral to sink.

Derelict fishing gear poses a serious and lethal threat to macrofauna in environments where this debris is present. The reef communities of the NWHI include protected species and other wildlife. All marine turtles that occur in Hawaiian waters have documented entanglement records including the endangered hawksbill (*Eretmochelys impricata*), olive ridley (*Lepidochelys olivacea*) and leatherback (*Dermochelys coriacea*) sea turtles, as well as threatened green sea turtles (*Chelonia mydas*). Entanglement in derelict fishing gear is also a known cause of mortality to the critically endangered Hawaiian monk seal (Fig. 100). All six extant breeding subpopulations of this seal are located in the NWHI, and it suffers the greatest entanglement rates of any pinniped (seal or sea lion) reported to date. In addition to marine mammals and sea turtles, seabirds, fish, and crustaceans are also at risk from entanglement in derelict fishing gear, thus broadening the ecological scale on which this waste of resources occurs.

Goals and Objectives

To address these concerns, the Honolulu Laboratory (HL) has proposed a comprehensive multiagency program to assess, monitor, and mitigate the effect of marine debris on coral reef ecosystems of the U.S. Pacific Islands. The goals of this program are to:

- Assess the amount of marine debris present on the coral reefs of the U.S. Pacific Islands.
- Remove marine debris from coral reefs and beaches.
- Monitor debris accumulation on the coral reefs and beaches.
- Identify source fisheries responsible for debris recovered.
- Evaluate impacts of marine debris on coral reefs and protected species.
- Enhance public awareness and education of marine debris affecting the U.S. Pacific Islands.

Figure 100. A Hawaiian monk seal entangled in derelict fishing gear.

Major Research Activities

Assessment and Monitoring Program

In Situ *Sampling*–Annual in situ surveys of derelict fishing gear in the coral reef ecosystems of the NWHI have been conducted since 1996. Surveys have utilized HL's research vessel as the primary support platform. FY 2000 accomplishments included extensive reef surveys at Pearl and Hermes Reef (PHR) and Lisianski Island (LIS). Reconnaissance surveys were also completed at Kingman and Palmyra Atolls and Jarvis, Howland, and Baker Islands in FY 2000. To date, extensive reef surveys have been conducted at four atolls in the NWHI: French Frigate Shoals (FFS), PHR, LIS and Midway Island. The surveys are conducted in partnership with the U.S. Fish and Wildlife Service (USFWS) and the representative state and territorial governments. Key parameters documented during surveys include the type of debris (net or maritime line as well as net type: trawl, seine, gill, etc.), size, distribution, and density. Debris location is noted using the GPS and debris is documented by still and video photography. After in situ documentation, debris is removed to mitigate coral reef damage and wildlife entanglement as described below.

The most frequent type of derelict fishing gear encountered in the NWHI is trawl netting. Debris ranging in size from less than 5 m^2 to greater than 25 m^2 has been documented. Measured debris densities range from 1 to 63 pieces of debris per km^2. FY 2000 research also confirmed that areas of greatest debris density at PHR and LIS coincide with areas preferentially used by Hawaiian monk seals as nursery grounds, highlighting the need for continued mitigation of this problem to support the recovery of this critically endangered species. Preliminary results from other U.S. Pacific Islands suggest that the preponderance of North Pacific derelict fishing gear accumulates in the NWHI. Derelict fishing gear does not appear to be a significant threat to the coral reef ecosystems

of Kingman and Palmyra Atolls and Jarvis, Howland, and Baker Islands.

Plans for FY 2001 (pending new funding) include a 4-6 month effort of extensive debris removal activity in the NWHI. This will include additional debris surveys at PHR and Kure Atoll as well as revisiting previously surveyed sites at FFS and LIS to monitor debris accumulation and generate the first estimate of derelict fishing gear accumulation rates. Additionally, collections of unknown taxa encountered on debris will be used to document possible occurrence of alien species.

Remote Sensing–HL proposes to enhance collaboration between marine debris and coral reef research by investigating the use of aircraft and satellite-based remote sensing technologies to expand the spatial coverage and improve the temporal resolution of in situ coral reef surveys, including derelict fishing gear components. These efforts will be conducted in collaboration with other federal agencies, universities, and the private sector. HL has proposed to assist National Ocean Survey (NOS) in conducting reconnaissance surveys at select sites in the NWHI using panchromatic and hyperspectral or multispectral imaging sensors in FY 2000. More thorough aerial mapping of the NWHI is planned by NOS in FY 2001. By using different spectral channels it is possible to identify specific spectral signatures of features otherwise indistinct in the visible range. Use of specific channels or a combination of channels will make it possible to discern between marine debris, algae, corals, and sand once the ground-truth work links the features to their respective spectral signatures. The development of oceanographic products from satellite-based sensors to assess and monitor HL and CoastWatch scientists (Fig. 101).

Marine Debris Cleanup Program

The marine debris program will support the HL's proposed Coral Reef Restoration Program through the mitigation of debris damage to the coral reefs of the U.S. Pacific Islands. Initial efforts will focus on expanding

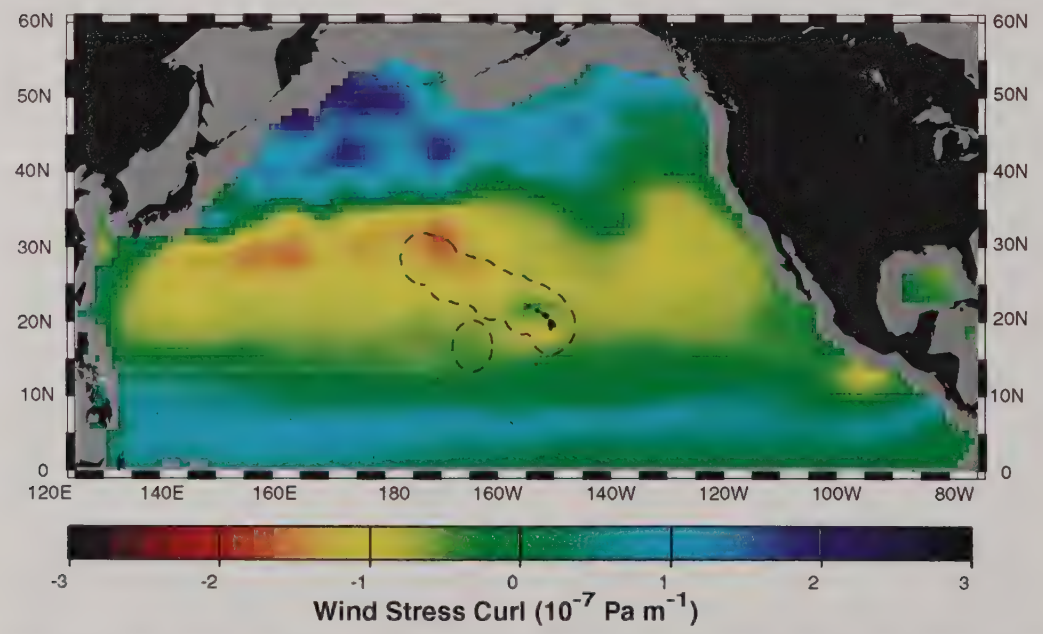

Figure 101. The spatial distribution of oceanic convergence during Boreal winter in the region of the Northwestern Hawaiian Islands as determined using wind stress curl from satellite measurements from 1991-99. Negative wind stress curl indicates region of convergence and likely debris accumulation.

Figure 102. A NMFS diver removes derelict fishing gear from Northwestern Hawaiian Islands coral reef.

the existing HL-led multi-agency cooperative efforts to remove marine debris from the coral reefs and beaches of the NWHI. These efforts were initiated in the early 1980s to reduce mortality and morbidity of endangered Hawaiian monks seals observed entangled in these nets an average of 15 times annually. In 1996, these efforts were expanded to include coral reef habitats, in addition to NWHI beaches. In addition to monk seal entanglements, this work revealed extensive damage to coral reefs and Essential Fish Habitat by marine debris. Debris removal efforts were greatly facilitated in 1998 by partnering with the U.S. Coast Guard, U.S. Navy, USFWS Office of NOAA Corps Operations, University of Hawaii Sea Grant Program, Hawaii Coastal Zone Management Program, University of Alaska Marine Advisory Program, City and County of Honolulu, University of Hawaii, Center for Marine Conservation, Hawaii Wildlife Fund, Natural Resources Consultants, Browning Ferris, Inc. (BFI) and NET Systems, Inc. This successful partnering earned Vice President Al Gore's National Performance Review (NPR) Silver Hammer Award which showcases examples of teamwork, innovation, and creativity in the Federal government. In total, these cooperative efforts have removed over 35 tons of marine debris from NWHI coral reefs (Fig. 102). Future activities will continue to focus on multi-agency cooperation from all sectors.

In October 2000, HL will lead another multiagency cooperative marine debris removal effort to PHR, LIS, FFS, and Kure Atoll. Two 4-6-month marine debris removal expeditions are proposed for FY 2001 and FY 2002. Possibly utilizing a larger, helicopter-equipped vessel dedicated to debris removal, these expeditions are projected to remove marine debris from 75% to 80% of the reef habitat of the NWHI. These efforts will focus on prioritizing regions and cleanup strategies to maximize efficiencies and benefits to overall ecosystem health, but depend on new funding.

As part of the coral reef assessment and

monitoring activities of the other U.S. Pacific Islands, marine debris surveys and removal activities will be conducted. Whenever possible, removal activities will continue in partnership with other Federal, state, territorial, and local agencies, as well as many non-government organizations.

Protected Species Recovery and Coral Reef Protection Program

HL has proposed a plan to enhance protected species recovery and protect U.S. Pacific Island coral reef ecosystems consisting of three primary components: 1) identification of derelict fishing gear and its source, 2) remote sensing to track and interdict marine debris at sea before it damages coral reef ecosystems, and 3) public awareness and education. Each of these preventive efforts is aimed at reducing the source of marine debris available to damage coral reef ecosystems and hinder recovery of protected species.

Efforts are underway to identify the sources of derelict fishing gear based on gear types, materials, and construction methods (Fig. 103). These identification efforts will be increased, and national and international efforts must be taken to characterize fishing gear so that the sources of marine debris can be positively identified. The HL intends to publish a catalog for identification of derelict fishing netting.

A significant amount of marine debris continually circulates around the North Pacific ocean gyre. Eventually, this debris grounds on coral reefs and disrupts the ecological balance of the reef community. The region of marine debris accumulation can be remotely observed using a combination of several satellite-based sensors (scatterometer [winds], AVHRR [temperature], SeaWiFS [ocean color] and TOPEX/Poseidon [sea surface height]) to guide aerial and shipboard reconnaissance for removal of the debris at sea. Figure 104 illustrates the dynamic nature

Figure 103. NMFS scientists onboard the USCG Cutter *Walnut* analyze and catalogue derelict fishing gear by net type.

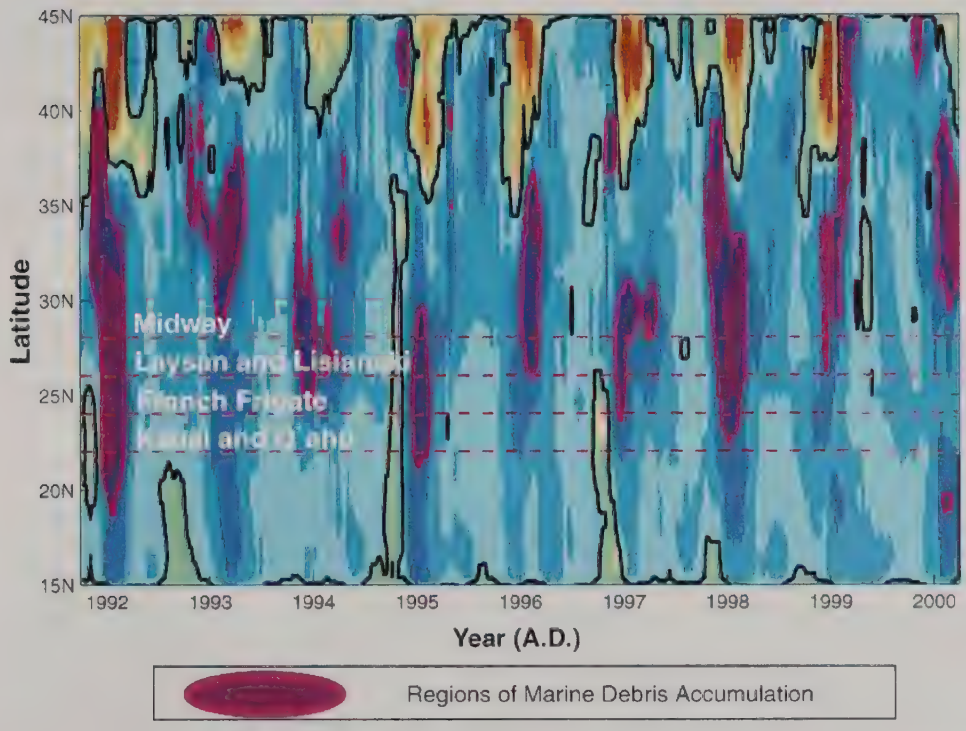

Figure 104. Time series of wind stress curl for region associated with the NWHI (180 to 160W). Negative wind stress curl represents oceanic convergence and likely concentration or accumulation of marine debris.

of the subtropical convergence zone based on satellite remote sensing. In certain years (notably 1992 and 1998, during which El Niño conditions dominated much of the Pacific basin), the subtropical front crosses the Hawaiian Archipelago, allowing for increased rates of accumulation of marine debris on the Hawaiian land margins. This information will also be used to help identify source regions.

Finally, recent efforts to educate the public about the marine debris problem will be continued and expanded. Efforts will focus on educating the commercial fishing and maritime industries about the damage to coral reef ecosystems by marine debris and on efforts to minimize future damage by reducing or eliminating the source. All aspects of this plan must involve collaboration with other Pacific Rim countries to ensure the long-term success of coral reef ecosystem conservation and protection in the Pacific Ocean.

International Marine Debris Conference on Derelict Fishing Gear and the Ocean Environment

HL was the leading contributor to an international conference on derelict fishing gear in the ocean environment. The goal of the conference, held August 6-11, 2000 at the Hawaii Convention Center, was to convene international experts to evaluate the sources and ecological impacts of derelict fishing gear on coral reef and other marine ecosystems, with emphasis on the Pacific Ocean, and to recommend mitigation and prevention strategies based on environmental, economic, and political realities. The specific objectives of the conference included:

- Review sources and impacts of derelict fishing gear.

- Assess and identify new technology for mitigation and prevention.
- Establish international and national partnerships to address the issue of marine debris.
- Increase national and international public awareness of derelict fishing gear by recommending political and educational strategies that will establish a stronger stewardship ethic for all stakeholders.
- Develop recommendations to prevent future impacts to marine ecosystems by derelict fishing gear (Fig.105).

Figure 105. A Hawaiian monk seal resting on derelict fishing gear risks entanglement.

Advancements in Oracle Database System, GIS, and Oceanic Satellite Remote Sensing Applications

BACKGROUND

The Honolulu Laboratory (HL) has made significant advances in the conversion of its data holdings to the Oracle database system, in the development of capabilities for using Geographical Information Systems (GIS), and in the expansion of satellite remote sensing data available through the NOAA CoastWatch Site to applications in fisheries and protected species research.

ORACLE DATABASE AND GIS DEVELOPMENT

Background Information

HL committed to use Oracle for developing an online, relational database system in response to the NMFS decision to adopt Oracle as the agency standard. Initially, efforts were devoted to developing a fully relational database model using pelagic fishery databases as a starting point. The development of standard user products; e.g., summary reports, then received some emphasis, eventually leading to a major effort to implement user access to HL database holdings via the Worldwide Web (WWW). This required considerable work on developing data browsing capabilities and data products, as well as upgrading basic Oracle database software, Oracle designer packages, Oracle developer packages, and Oracle Web Server software. Recently, efforts have concentrated on developing Oracle-based data entry applications, loading historical data sets into Oracle, developing browser applications for specific data sets, developing alternative ways of downloading data, and exploring alternative means of implementing database security. Further work is needed on database design which was put on hold in order to devote limited resources available to the tasks noted above. The conversion to the Oracle system has been difficult and at times a frustrating task. However, due to the efforts of a dedicated, capable, and talented multidisciplinary team of HL staff, excellent progress has been accomplished. Nevertheless, significant work remains to be done.

The development of (GIS) capabilities is linked to the Oracle database conversion for accessing georeferenced data and storing processed GIS coverages. Moreover, the capacity for GIS technology is critical for research related to essential fish habitat (EFH), insular and pelagic ecosystems, coral reefs, and protected species.

Goals

The goals of the program to develop an Oracle database system and GIS capabilities are the following:

- Achieve an Oracle-based enterprise database for storing HL data holdings including those for 1) insular and pelagic fisheries, 2) oceanographic and environmental research and monitoring, and 3) protected species (e.g., Hawaiian monk seal, sea turtles, and seabirds).

- Access to HL database via the WWW by HL and other NMFS scientists and managers, as well as by the Western Pacific Regional Fishery Management Council (WPRFMC) and other users to conduct scientific analyses, compile summary data, and prepare reports.

- Use of GIS technology linked to Oracle for distributing data products to users and in ecological research required for providing scientific advice for the management of marine resources and for the recovery and management of protected species.

Objectives

The current objectives of the HL Oracle conversion and GIS development include:

- Expand access to HL database holdings via the WWW by improving and simplifying the online data catalog, data browsers, data summary, and data extraction

tools and by providing training on using these applications.

- Expand utilization of the Oracle database system for accomplishing offline, legacy processes; e.g., data entry, quality control, and data updating.
- Develop and implement a data security system for controlled access to appropriate data sets.
- Address confidential and proprietary data issues, identify appropriate data sets, and improve controlled access by qualified users.
- Develop and implement a revised enterprise model, with simplified data loading requirements, improved responsiveness, and other enhancements.
- Expand GIS library of basic map data and establish a data library of georeferenced data sets to support a wide range of GIS applications.
- Link georeferenced fisheries, protected species, environmental, and map data to develop GIS applications supporting fishery management and protected species research needs.
- Provide user guides and training on accessing and using ArcView and the HL GIS coverage library for research and management purposes.
- Participate the NOAA coral reef initiative.

Major Accomplishments

Monk Seal

- Applications for data entry, checking, updating, report preparation, and downloading are operational.
- Field entry of data into PC-based Oracle databases has been developed and is being utilized during the 2000 field season.

Lobster Observer

- Applications for data entry, data validation, and output to ASCII by NMFS scientific observers are operational.
- Oracle data entry forms and quality control procedures have been updated for the proposed 2000 lobster experimental fishing program.
- Design and implementation of a complete remote data entry, validation, and downloading to ASCII applications completed for use by NMFS scientific observers via the WWW for the proposed 2000 experimental fishing program.

Longline Observer and Logbook Data

- NMFS observer and Federal logbook data loaded in the Oracle database are accessible via the WWW for querying, downloading, running of standard and ad hoc reports, and displaying geographical plots.
- Capabilities developed to match longline sets reported in logbook records with sets in observer records using an Oracle Forms application and the data incorporated into the Oracle database for user linking.
- Application for remote Web-based data entry, data validation, and downloading of data and validation reports designed and implemented for use by NMFS observers.

Other

- Data catalog of data sets loaded into the Oracle database are available via the WWW using Oracle forms.
- More than 50 historical data sets have been loaded into Oracle with Oracle forms for querying and downloading.
- Upgrades completed to Oracle Web Server software, Oracle Developer software, and all forms and reports dependent on them.
- Two upgrades completed to the Oracle database software.

- Java-based applications developed for quick downloading of data for predefined user specifications.

- Several alternative means of providing data security have been explored at the Oracle database and Web server levels involving Oracle and other tools. Work on this topic is continuing.

HAWAII COASTWATCH

Background

The Hawaii Regional CoastWatch Node (HRCWN), funded by NOAA/National Environmental Satellite, Data, and Information Service (NESDIS), is located at the HL. It serves as a regional focal point for the acquisition and processing of remotely sensed environmental data and the timely distribution of derived products to marine researchers, resource and crisis managers and the general public. In addition to operating a direct readout station for data from NOAA Polar-orbiting operational environmental satellites, the HRCWN also receives and processes data streams from other space-borne instruments that measure surface ocean winds, sea surface height, ocean color, and several alternate forms of sea surface temperature. With these systems in place, HRCWN is able to offer a full suite of satellite oceanographic products which cover all the US Pacific Island Exclusive Economic Zones (EEZs). Applications of these products appear throughout this document.

Goals and Objectives

- Acquire real-time Advanced Very High-Resolution Radiometer/High Resolution Picture Transmission (AVHRR/HRPT) satellite data for the central Pacific region.

- Produce AVHRR-based satellite oceanic data products for areas in the main Hawaiian Islands, and the Northwestern Hawaiian Island Archipelago, as well as other portions of the central Pacific on request.

- Process near real time data streams such as ocean surface topography, ocean surface winds, and ocean color.

- Develop new satellite products for fisheries, protected species and other applications.

- Distribute satellite oceanic data products to registered CoastWatch users and National Ocean Data Center (NODC) archives.

Accomplishments and Activities

This past year has been truly outstanding for the HRCWN with excellent progress made in a number of areas:

- Development of new satellite-derived ocean products.

- Substantial progress in data fusion with data from several satellite sensors.

- Added many new applications for fisheries and protected species.

- Expanded the area of coverage to include all U.S.-affiliated Pacific Island EEZs.

- Added a large number of new registered data users.

Data Acquisition

Unlike most CoastWatch sites where processed AVHRR data are provided by NESDIS from a central location in the Washington, D.C. area, the HRCWN acquires AVHRR/HRPT data directly from NOAA polar-orbiting satellites using a ground readout station operated by the NWS in Hawaii. This is the only means for obtaining operational, high-resolution AVHRR ocean products for the central Pacific. All processing of the AVHRR/HRPT data and product generation are performed at the HRCWN, as well as product distribution and routing of products for archival at the NCAAS. An example of the AVHRR sea surface temperature product is shown in Figure 106.

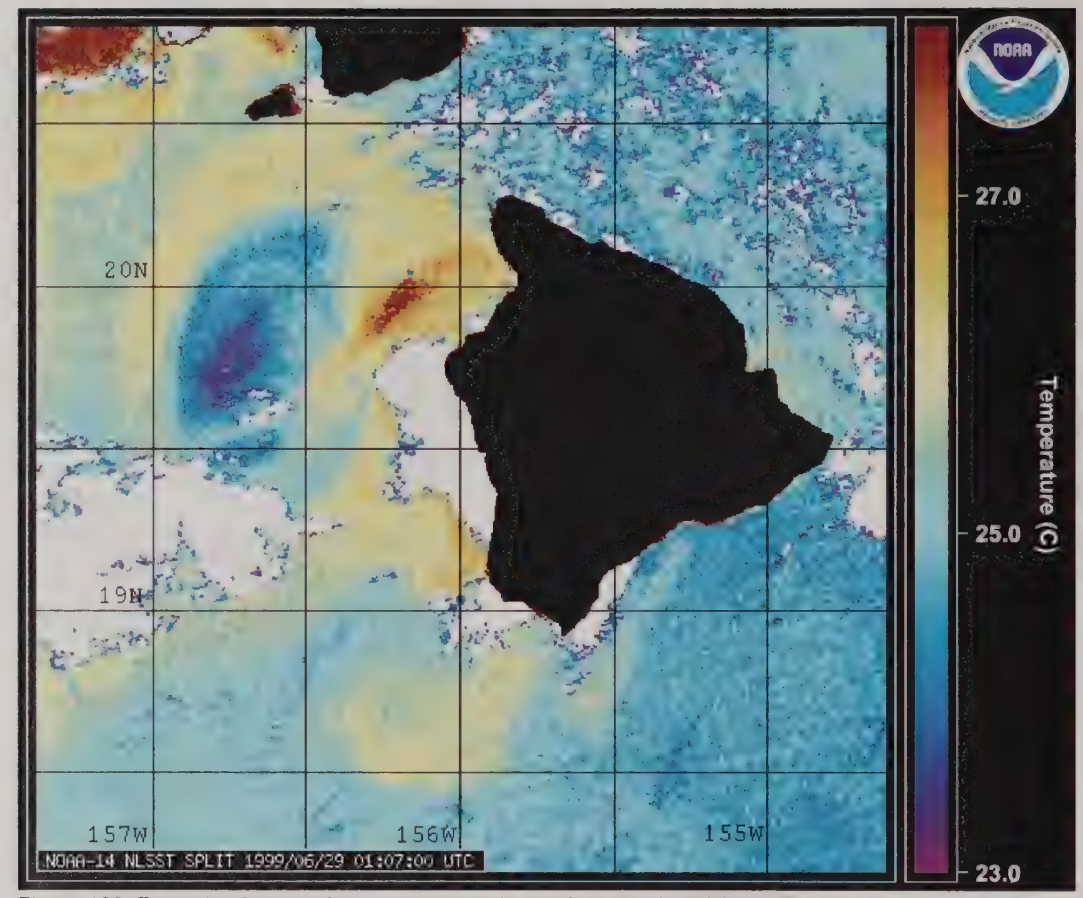

Figure 106 Example of sea surface temperature image from the AVHRR HRPT data stream.

Additional near-real time data streams are acquired and processed by other facilities. These data are then transferred via the internet to the HRCWN, where additional specialized processing is performed. While the HRCWN now maintains many such data streams, four are of particular interest:

- TOPEX altimetry from NESDIS/Oceanic Research Applications Division (ORAD) and NASA/Jet Propulsion Laboratory (JPL).
- Governmental Operational Environmental Satellite (GOES) sea surface temperature from NESDIS/ORAD.
- QuikSCAT ocean surface wind vectors from NESDIS/ORAD.
- SeaWiFS phytoplankton pigment concentration from NASA/Goddard Space Flight Center (GSFC) (2-week delay).

A montage of some data products is shown in Figure 107.

Regional Coverage

Satellite-based SST products are prepared for the main Hawaiian Islands, the Northwestern Hawaiian Island archipelago, portions of the North Pacific Transition Zone (NPTZ), Johnston and Palmyra Atolls, Station ALOHA (NSF research site), Guam, the CNMI, and American Samoa. In addition to the near real time data acquired from NOAA/NESDIS, long term, scientific-quality, data sets have been acquired for SST,

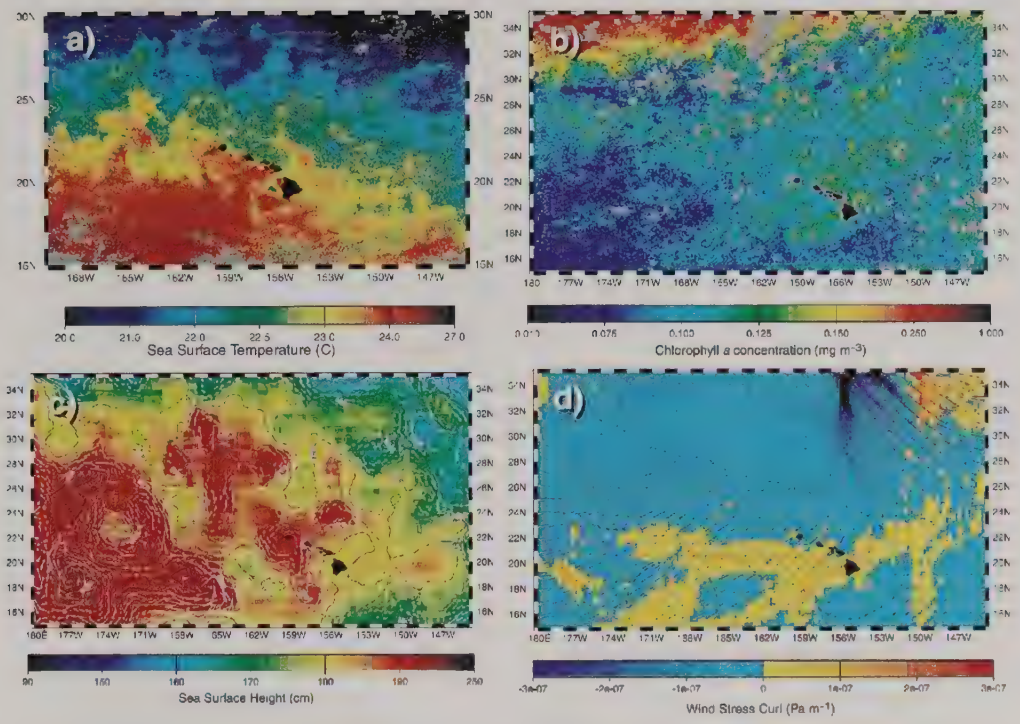

Figure 107. Sample satellite data suite for the Hawaiian Archipelago. a) 2-day sea surface temperature from the GOES-10 spacecraft; b) Chlorophyll *a* concentration from the Orbview-2 spacecraft; c) Sea surface height from the TOPEX/Poseidon spacecraft and geostrophic current vectors; d) Wind stress curl and wind stress vectors from the QuikSCAT spacecraft.

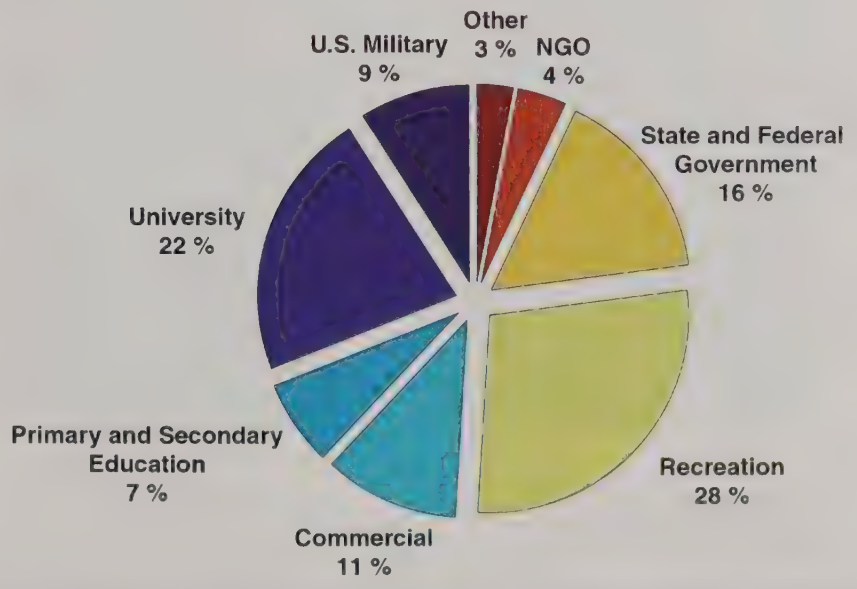

Figure 108. Composition of CoastWatch Data Users US Military includes US Navy, US Army and US Coast Guard. There are presently 223 registered HRCWN data users

sea surface height (SSH), ocean color and ocean wind data sets. From these data sets, the HRCWN has developed climatologies that permit the user to place the near real time data within a historical context of the regional ocean dynamics.

Data Users

During the past two years, the number of HRCWN data users has increased nearly ten-fold from 25 to 223. The composition of the HRCWN data user pool is shown in Figure 108. The enhanced infrastructure realized in FY 1999 and FY 2000 have resulted in significant extension and improvement of HRCWN data products and customer services.

Product Development

A measure of success of the HRCWN is illustrated by the proliferation of satellite-derived images which occur throughout the various sections of this document. This is due partly to the supportive infrastructure maintained by CoastWatch, enabling data users to easily acquire and utilize these typically large spatial data sets. The HRCWN is also committed to working with users to develop products that have specific applications. An example of this is the new ocean convergence product (Fig. 109). This product uses ocean surface wind data from the ERS-1 and ERS-2 scatterometers to calculate wind stress curl and the resulting Ekman transport to identify regions of oceanic divergence and convergence. Other indicators include the 0.2 mg m^{-3} chlorophyll *a* contour from the SeaWiFS ocean color instrument and the 18C SST isotherm from AVHRR instruments. The three variables are displayed as a time series to emphasize the dynamic nature of convergence area. This product and others like it are used to identify and monitor Essential Fish Habitat and to identify regions where marine debris will accumulate. As new data streams become available, they will be incorporated into the HRCWN data suite to further enhance the service we provide.

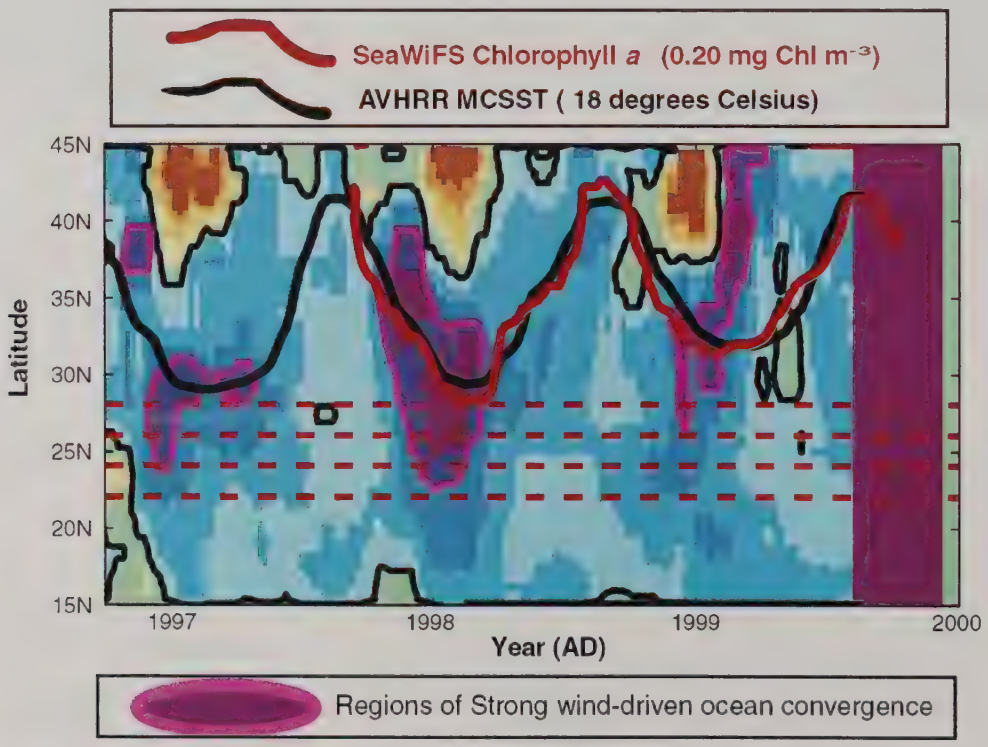

Figure 109. Ocean Convergence product showing time series of wind stress curl for satellite winds from the ERS-2 scatterometer, the 0.2 mg m^{-3} SeaWiFS chlorophyll *a* isoline and the 18 degree C SST isotherm from AVHRR.

APPENDIX A

HONOLULU LABORATORY PUBLICATIONS
(From October 1999 through September 2000)

Aguirre, A. A., J. Vasconcelos P., T. R. Spraker, P. Hernandéz S., B. Zimmerman, E. Albavera P., E. M. López R., and G. H. Balazs.
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Balazs, G. H., I.-J. Cheng, and H.-C. Wang.
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In press. Remigration and residency of Hawaii green turtles in coastal waters of Honokowai, West Maui, Hawaii. *In* Proceedings of the Twentieth Annual Symposium on Sea Turtle Biology and Conservation, February 29-March 4, 2000, Orlando, Florida. U.S. Dep. Commer., NOAA Tech. Memo. NMFS-SEFSC.

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